DIVISION OF AGRICULTURAL SCIENCES
UNIVERSITY OF CALIFORNIA

A Simulation Model of Grower-Processor Coordination in the Beet Sugar Industry

by
James N. Niles
and
Ben C. French

CALIFORNIA AGRICULTURAL EXPERIMENT STATION
GIANNINI FOUNDATION OF AGRICULTURAL ECONOMICS

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A SIMULATION MODEL OF GROWER–PROCESSOR COORDINATION IN THE BEET SUGAR INDUSTRY

by

James A. Niles[1] and Ben C. French[2]

INTRODUCTION

A major factor affecting the efficiency of producing and marketing processed agricultural products is the manner of coordinating grower and processor activities. This involves determining how much to produce, what qualities to produce, where and when to plant, when to harvest, and how to allocate quantities among factories. Decisions made at one level or at one point in time influence the performance of the system at other levels and other points in time. For example, if quantities planted exceed factory capacities, growers may be unable to sell all of their product, or they may have to defer harvesting and so affect the yields and quality of their product and possibly interfere with other farming activities. On the other hand, if the flow of product from farm to factory is irregular, processing costs may be increased because of higher inventory levels, increased waiting time, possible overtime, and changes in product quality. The coordination of the activities is usually made difficult by uncertainties as to weather and biological factors which influence growth rates, yields, and the ability to perform harvest and assembly operations at desired times.

This study develops a model which simulates via computer the operations of a sugar beet production–processing system consisting of a single processor (with four plants) and approximately 1,000 associated growers. The 180,000 acres of beets included in the system (more than half of the California total) is a significant component of the agricultural industry of the state. Similar models could be constructed for other sugar beet systems, and the general analytical framework and quantitative approaches appear applicable to many processing commodities.[3]

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[1] Assistant Professor, Food and Resource Economics Department, University of Florida, Gainesville.

[2] Professor of Agricultural Economics and Agricultural Economist in the Experiment Station and on the Giannini Foundation, University of California, Davis.

[3] If we were attempting to design a model for the entire state, we would, of course, have to take account of interactions among processing firms. Actions and organization which appear optimal for the single system may not be optimal (with respect to the public interest) for the industry as a whole. In practice, an industry–wide optimum may be very difficult to achieve in the absence of any central planning authority.

The study has three main objectives. The first is to formulate an analytical framework for measuring cost and efficiency relationships associated with the scheduling component of producing and processing agricultural commodities. This involves time, quality, and uncertainty dimensions that have been largely neglected or assumed away in traditional theoretical models of production which have focused only on parts of total systems. The second objective is to provide a basis for evaluating the effects of changes in the system on costs and returns to both producers and processors. The model developed serves as a tool for an improved system design and for evaluating the efficiency of the present system. The third objective is to suggest ways in which some tools of management science––particularly computer simulation and linear programming––may be used to formulate improved decision rules and to choose among alternative decision strategies.

The first section of the report presents a brief description of the sugar beet industry of California. With this background, we then describe the specific production–processing system to be studied. This is followed by an explanation of how we formulated the computer model which simulates the economic behavior of this system. We then show how the model may be used to evaluate potential gains (or losses) to growers and processors from changes in decision rules or alterations of the system. The final section reviews the implications of the analysis with respect to the efficiency of the present system and the potential value of further research along these lines.

It is important to note that scheduling and allocation rules which are optimal for the processor conceivably may be less than optimal for individual growers, the degree of divergence depending on the location and environmental factors affecting each grower and the contractual arrangements under which growers are paid for their product. The efficiency of a coordination system thus may vary with one's point of view. The public interest usually is best served by a system which minimizes the combined costs associated with the total production–processing system. Equity considerations may suggest contractual arrangements which compensate producers who would otherwise incur higher costs or reduced returns under an improved total system. In any case, the analysis of any coordination system must consider these potentially diverse interests.[1]

THE CALIFORNIA SUGAR BEET INDUSTRY

Sugar beets are a major California crop. In 1971 it was the tenth leading farm product with an annual contribution of about $126 million to the state's economy [2]. California leads all states in sugar beet production. In the calendar year 1972, 31 percent of the production and 28 percent of the harvested acreage of the United States were in California. The comparable figures for 1968–1972 are shown in Table 1.

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[1] In a complete social welfare analysis, we would also need to consider the effects of alternative systems on other interests such as labor and resource utilization. The impact would appear to be rather minor in this case.

TABLE 1

Harvested Acreage and Production of Sugar Beets
in California and the United States
1968-1972

Harvest year	California					United States		
	Acreage			Production		Acreage		Production
	1,000 acres	percent of U. S. acreage	average tons per acre	1,000 tons	percent of U. S. total	1,000 acres	average tons per acre	1,000 tons
1968	254.2	18.0	23.9	6,081	24.0	1,410.0	18.0	25,363
1969	305.2	20.0	19.8	6,046	21.8	1,540.5	18.0	27,736
1970	320.5	22.7	26.0	8,342	31.6	1,413.3	18.7	26,378
1971	346.5	25.9	23.6	8,165	30.2	1,339.6	20.2	27,044
1972	326.0	24.2	27.5	8,965	31.4	1,345.8	21.2	28,523

Source: U. S. Statistical Reporting Service, Crop Reporting Board, Crop Production, Annual Summaries.

Sugar beets are grown from Imperial County in the south to Tehama County in the north. The leading counties of production are Imperial, Kern, Yolo, San Joaquin, Fresno, Solano, and Monterey. Table 2 shows each county's harvested acreage, percent of totals, tons per acre, percent of sugar, and number of farming units for the 1970 crop.

Cultural Factors

The sugar beet (*Beta Vulgaris L.*) is a biennial plant. In the first year, the beet puts on top growth and then follows with the development of a large taproot where the sugar is accumulated. In the next year, a seed stock shoots up (known as bolting), and the plant may utilize the sugar reserves accumulated in the previous year. Beets are typically harvested prior to the end of the first growing season; but in northern areas of California, beets may be "overwintered" and harvested in the spring, ideally before bolting.

The sugar beet is a cool–season, cold–hardy plant. It grows best in areas where the temperatures are moderate. In the hotter areas of California's interior valleys, the crop is planted in the fall or winter and harvested in the late spring or summer.

Sugar beet production is measured in terms of tons of roots and pounds of sugar per acre. High sugar percentage is favored by cool night temperatures since lower temperatures are conducive to sugar storage by inhibiting its utilization for plant growth. In either warm or cool climates, sugar percentage can be increased by causing the plant to become deficient in nitrogen and, thus, restricting growth.

Beet production is subject to several types of diseases and insect pests which have important influences on yields and may restrict the location and time of planting. Of particular importance are three aphid–borne viruses––Beet Yellows, Beet Western Yellows, and Beet Mosaic. The California Department of Agriculture has estimated losses from these viruses as high as $21 million per year [3].

Efforts to reduce the effects of these viruses have included research to develop resistant varieties, determining best periods to apply insecticides, establishing planting times which reduce the possibility of disease infestation, and establishing beet–free areas to restrict the spread of diseases. Beet–free areas are areas where no beets are in the ground for a period of time. The harvest is completed before the heavy rains force a discontinuance of harvest in the fall (frequently a target date of November 1 is used). This practice eliminates the overwintered beets which serve as a source plant for the Virus Yellows carrying aphids. Beet–free areas are located far enough away from nonbeet–free areas to eliminate migration of the aphid.

Other diseases that are significant are Curly Top Virus and *Cercospora* leaf spot. The Curly Top Virus is spread by an insect vector, the beet leafhopper, *Cirulifer Tenellus*

TABLE 2

California Sugar Beet Production by County, 1970

County	Harvested acreage	Percent of California total: Acreage	Percent of California total: Tonnage	Average tons per acre	Average sugar percent	Number of farming units
Alameda	1,348.2	.47	.44	23.9	15.51	11
Butte	3,688.6	1.28	1.07	21.4	14.22	21
Colusa	12,823.1	4.45	3.97	22.9	16.16	55
Contra Costa	1,860.8	.65	.66	26.3	15.69	10
Fresno	25,387.0	8.82	7.32	21.3	14.65	79
Glenn	2,361.6	.82	.63	19.8	14.41	13
Imperial	58,877.0	20.45	20.82	26.1	16.59	186
Kern	28,816.3	10.01	9.99	25.6	14.00	140
Kings	8,726.3	3.03	1.87	15.8	14.66	21
Los Angeles	2,117.3	.73	.64	22.4	16.42	5
Madera	1,237.4	.43	.50	29.8	14.35	10
Merced	6,534.4	2.27	2.33	26.4	16.12	34
Monterey	14,764.1	5.13	6.86	34.3	16.28	143
Orange	629.5	.22	.21	24.1	13.96	7
Riverside	3,593.1	1.25	1.38	28.4	13.45	18
Sacramento	5,959.6	2.07	1.95	24.2	15.56	46
San Benito	1,168.0	.41	.44	27.7	15.54	25
San Bernardino	98.5	.03	.04	27.4	13.15	1
San Joaquin	28,291.9	9.83	11.60	30.3	16.08	198
San Luis Obispo	2,245.7	.78	.62	20.4	15.87	18
Santa Barbara	4,141.0	1.44	1.37	24.4	15.63	24
Santa Clara	784.5	.27	.30	28.3	15.84	10
Santa Cruz	168.5	.06	.08	32.9	16.53	5
Solano	21,159.2	7.35	7.53	26.3	16.40	113
Stanislaus	4,048.7	1.41	1.55	28.3	14.61	31
Sutter	4,853.2	1.68	1.72	26.1	15.97	18
Tehama	1,075.8	.37	.36	24.6	13.53	6
Tulare	10,069.7	3.50	3.26	23.9	13.53	80
Ventura	2,255.4	.78	.88	28.8	15.69	31
Yolo	28,827.7	10.01	9.61	24.6	15.96	115
TOTAL	287,912.1	100.00	100.00	25.3	15.65	1,474

Source: U. S. Agricultural Stabilization and Conservation Service, California, 1971 Annual Report, pp. 53-55.

(Baker). This disease nearly wiped out the industry in the 1920's before resistant varieties and a control spray program were adopted. The *Cercospora* leaf spot is caused by the fungus, *Cercospora Beticola,* which attacks the leaves of the beet.

Nematodes constitute the principal pest of the beets. The nematodes are small worms which attack the beetroot and stunt the growth. To reduce the danger of nematode infestations, a rotational program is required. A crop of sugar beets generally should not follow another crop of sugar beets. Since sugar beets are a deep–rooted crop often penetrating to 6 feet, it is a good crop to be used in a rotational program with shallow–rooted crops, benefiting from the previous crop's unutilized fertilizer.

Beet yields increase as the time interval from planting to harvesting increases. Sugar percent is affected by the time of harvest, principally, through the degree of nitrogen deficiency and temperature immediately prior to harvest.

In some areas of California, the time of planting may be restricted by the weather, by efforts to plant before or after certain dates to avoid disease infestations, and by the previous crop still being in the ground. To reduce the occurrence of Yellow Virus in the Delta and the Northern Central Valley areas, planting may be delayed until late spring after the peak of the aphid flights. In the Southern Central Valley, winter planting is encouraged to reduce Curly Top infestations, and late planting is discouraged to avoid nematode infestations.

Harvest and Assembly Operations

All sugar beets are harvested mechanically by diggers which convey the topped beets directly into trucks in the field. The beets are then either transported directly to a factory or, more commonly, to a country receiving station. At the receiving station the truck passes over a scale, and the weight of the truck and beets is determined. The beets are then dumped, screened, and conveyed into railcars, transports (trucks contracted by the processor to move the beets to the factory), or directly into storage if received at the factory. Dirt, small beets, and trash are eliminated by screens and rollers. This waste is collected and transported away by the processor.[1] The empty truck is then reweighed. The difference between the initial weight of the truck loaded with beets and the empty truck weight is the field or gross weight. The dirty or first net weight is this weight minus the quantity of waste removed.

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[1] The grower reimburses the processor for the expense of hauling this wastage away. This is called the dirt haul charge.

While the load is being conveyed, a sample is taken and sent to the tare lab for analysis. Here the beets are cleaned, the remaining tops (crowns) are removed, and the sugar percent is determined. A clean beet weight percentage is calculated expressing the clean weight after the dirt, leaves, and the crown have been removed over the original weight. This percentage is then applied to the first net to calculate the second net, clean, or purchase weight. This is the weight for which the grower is paid.

In most cases the grower is responsible for the delivery of the beets to the receiving station; but in cases where the grower transports the beets appreciable distances to the receiving station, he usually contracts with a commercial hauler to do this for him. The grower then experiences a grower's hauling charge based upon the distance and amount hauled. The processor reimburses the grower for part of this charge with a hauling allowance. In special cases where the processor has assumed this responsibility, the company pays the entire charge of a commercial hauler.

The beets delivered to the outlying receiving stations are loaded into larger trucks (transports) or into 70–ton railcars (gondolas) to be shipped to a factory.

The tonnage that is transported is the first net weight. During transit, the beets experience two types of loss––a weight shrink due to dehydration and a loss in sugar content due principally to respiration. The processor negotiates with the railroad to establish a shrink factor to establish tonnage for which the processor pays rail rates. This figure would represent the average percent weight loss during rail shipment.

The tonnage delivered to the factory is the first net weight minus the actual shrink loss during transit. The beets are placed into storage bins or piled on concrete slabs. These piles insure continuous operation as well as extend the time of factory operation.

While the beets are in factory storage, they may experience a further loss of sugar and change in weight. They might even increase in weight because of peculiar conditions, such as rainfall, that increase the moisture content. Similarly, when the beets are transported from the storage bins to the factory, they are transported in water flumes; hence, the moisture content may increase, increasing the total weight of the beets.

Factory Operations

There are four sugar beet processors with operations in California. Spreckels Sugar Division of Amstar Corporation operates four factories located at Spreckels (Salinas Valley), Manteca, Woodland, and Mendota. Holly Sugar Corporation has four plants located at Hamilton City, Tracy, Santa Ana, and Brawley. American Crystal Sugar Company has one plant at Clarksburg, and Union Sugar Division of Consolidated Foods Corporation has one plant located at Betteravia (near Santa Maria). Together these 10 refineries have a daily capacity of 40,100 tons of beets [4, p. 6].

Beet factory operations in California occur in two periods referred to as the "fall campaign" (July until weather shutdown in December or January) and the "spring campaign" (February–June). The winter period, when plants are shut down, is called the

"intercampaign." A thorough maintenance program is usually conducted in the latter period.

When a factory first starts to operate, it takes about two days to prepare it to receive beets to process (starting the lime kilns and building up the CO_2 production, etc.). These days are called "test–out" days. After this, the plant is normally operated at full capacity for 24 hours per day unless there is a shortage of beets. It is possible to continue to run the factory during short breaks in beet supply if a new supply is expected soon. These days of short supply are called "lay–by" days. The time required to shut down a factory after the last quantity of beets has been sliced is also called lay–by days.

The function of the factory operation is, of course, to transform sugar beets into sugar and by–products, such as beet pulp and molasses. Since the technical processes by which this is accomplished are not important to the development of the scheduling and allocation model, they will not be discussed here.[1]

Contract Arrangements

In California all sugar beets are grown under contract with the sugar beet processors. These contracts, signed prior to the growing season, contain both price and nonprice provisions.

The price provision centers around the price participating feature of the contract. The grower payment per ton of beets produced is based on the sugar percent of the beets and on the net return or net selling price (N.S.P.) of the processor. The N.S.P. is determined by taking the average gross selling price per cwt. of sugar for the year, as obtained by the processor, and then subtracting the excise tax and all marketing costs––freight, brokerage, cash discounts, insurance, storage, and advertising––as incurred by the processor.[2] A simplified schedule is shown in Table 3. The share of the N.S.P. that the producer and processor receive can be analyzed by the method suggested in Jackson [10] and Jackson, *et al.* [9]. Assuming a recovery rate[3] of 87.1 percent, an N.S.P. of $9.00 per cwt., and a sugar percent of 15 percent, the gross return to both the processor and producer would be $23.52 per ton of beets delivered.[4] Of this, the producer receives $14.37 or 61.1 percent, with the processor receiving $9.15 or 38.9 percent. These percentages remain approximately the same for all values in Table 3.

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[1] For further description of the processing operation, see Niles [7] and McGinnes [6].

[2] See discussion of government influences, *infra*, page 10.

[3] Recovery rate is the rate of sugar extraction at the factory and in this case based on the purchase weight.

[4] This figure is computed by multiplying $9.00 per cwt. x .15 x 20 cwt. per ton x .871 which equals $23.52.

TABLE 3

Grower Payment Schedule for Sugar Beets

Net selling price of processor	Payment to grower associated with sugar percent of:		
	13	15	17
dollars per cwt. of sugar	dollars per ton		
8.50	11.73	13.62	15.54
9.00	12.38	14.37	16.39
9.50	13.03	15.12	17.24

Source: Spreckels Sugar Division.

The grower receives an advance payment based on the expected N.S.P. shortly after delivery of the product, with the final payment made after the marketing year is completed and the N.S.P. determined.

The principal nonprice provisions of the contract pertain to delivery location and date, who furnishes beet seed, product delivery specifications, payment of transportation costs, right to inspect the crop, how sugar content is determined, dues deductions, and pesticide limitations.

The sugar beet processors employ fieldmen who work closely with the growers. Activities of the fieldmen include contracting, the coordination of the physical product flow from the producer to the processor, management assistance, and public relations for the processor.

Government Influences

The sugar beet industry is subject to a number of government influences. Of particular relevance to this study are production allotments known as "proportionate shares" based primarily on growers' history of production in recent years and the "conditional payments" received by growers who comply with the provisions of the U. S. Sugar Act.

The allotment programs and conditional payments are administered through the state and county Agricultural Stabilization and Conservation Service (ASCS). When beet production is restricted, the local ASCS, following regulations and procedures of the U. S. Department of Agriculture (USDA), determines which farmers can grow beets and how many acres. Beet acreage has not been limited in this manner since the 1966 crop.[1] In other years production is determined entirely by the contractual arrangements between the producer and processor.

Conditional payments are based on the amount of commercially recoverable sugar. An average recovery rate of 87.1 percent at the time of the study is used to determine an average commercially recoverable amount of sugar from each grower's gross sugar production.[2] The rate of conditional payment is on a sliding scale that depends upon the amount of sugar produced. On the first 350 tons, the rate is 8 cents per pound and

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[1] Acreage limitations were established in October, 1969, for the 1970 crop. However, these were rescinded in April, 1970, because of lower than anticipated sugar from the 1969 crop and indications that the total plantings would be less than the acreage tentatively allocated for the 1970 crop.

[2] The applicable recovery rate is the average computed by the U. S. Department of Agriculture for all sugar beets marketed under the "individual test" contracts in the United States. Individual test contracts are those where each load delivered is sampled for sugar content. It is a five–year moving average which was 87.1 percent at the time of the study and is based on the purchase weight of the beets delivered.

drops progressively to 3 cents per pound for all sugar produced in excess of 30,000 tons. In recent years conditional payments to California growers have averaged slightly above $2.00 per ton of beets purchased by the processor.

To qualify for the conditional payment, a grower must pay wages that equal or exceed the minimum rate specified by the USDA; employ no child labor; and in years when acreage is restricted, plant no more than his allotted acreage.

The money for this payment is obtained by levying an excise tax against the processors and refiners (approximately ½ cent a pound of sugar). The program has resulted in collections exceeding all expenditures, including the cost of administering the program, with the surplus being retained by the Treasury.

The Secretary of Agriculture also determines each year whether the price paid by the processor is "fair and reasonable" and whether the terms of the contracts are equitable. Sugar beet contracts are submitted annually to the USDA, and an analysis is made with regard to cost data on production and processing obtained by a field survey.

SPRECKELS SYSTEM

The system to be modeled in this study is the California operations of the Spreckels Sugar Division. As noted previously, Spreckels operates four factories and contracts with approximately 1,000 growers who produce about 180,000 acres of sugar beets. This system was selected for study because of its importance to California and the willingness of Spreckels to cooperate by providing data and technical information.

Factory and District Organization

For operational purposes, Spreckels has organized its activities into four districts which are further divided into 35 contract areas. Each district centers primarily around one of the four factories.

The Mendota District (D–4) contracts for beets in the central and southern San Joaquin Valley––the area south of Manteca. Presently, it is the largest operating district with 85,000 acres or 50 percent of the total. There are 14 contract areas and 13 receiving stations.

Planting occurs from October to June. Harvest starts in the Bakersfield area around July 1 and continues northward as time progresses, moving into the lighter soils as the winter rains slow harvest. Harvest is resumed in the spring in the extreme northern areas.

D–4 is the first district to start harvesting and supplies all four factories for the initial periods. As other districts start to harvest more, the shipments of D–4 beets decline until D–4 is supplying only Mendota Factory (F–4). F–4 is the newest factory (completed in 1963) with a rated capacity of 4,200 tons per day.[1]

The Spreckels District (D–1) contracts for beets in the Salinas Valley area, stretching down to the Santa Maria area. The Imperial Valley has been placed in this district for administrative purposes. The Salinas Valley has been historically California's most important sugar beet producing area. It has a better climate (cooler) than the other valley areas, so the yield is considerably higher. However, urban expansion and the switch to highly intensive crops has resulted in the decline in acreage in this area.

There are five contract (production) areas in D–1 with six receiving stations. This district accounts for approximately 18,000 acres or 11 percent of Spreckels' California acreage.

Planting occurs in this district from November to March, with harvest starting in August and continuing until completed in the Fall (about November 1). Imperial Valley beets are planted in September and October and harvested in April to June. The Imperial beets contracted by Spreckels are processed at the Mendota Factory (F–4) after D–4's local harvest has been completed. In July the Spreckels Factory (F–1) receives beets from D–4, gradually becomes self–sufficient on D–1 beets, and then receives beets from D–3 (Woodland). In the spring, it is run almost exclusively on D–3 beets.

F–1 is Spreckel's largest factory with a rated capacity of 6,500 tons per day. It was built in 1899 when there were more sugar beets grown in the area and is now out of proportion with respect to the acreage contracted by Spreckels in the area. To utilize this capacity, beets are shipped into this factory from other areas after local harvest has been completed. Otherwise, this factory would be shut down.

The Manteca District (D–2) contracts for beets from the Manteca area on the south to the Sacramento area on the north. There are seven contract areas and three receiving stations. This area has approximately 25,000 acres or 15 percent of the total.

Harvest starts around September 1, with harvest of the beet–free areas completed around November 1. Harvest continues until rain prevents harvest and resumes in the spring when the ground becomes dry enough.

The Manteca plant starts on D–4 beets and gradually shifts to D–2 beets as local harvest increases. By November 1, it is self–sufficient and remains so through the following spring. The Manteca Factory (F–2) was erected in 1917 and possesses a rated capacity of 4,200 tons per day.

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[1] Rated capacity is the quantity of beets processed under "normal" 24–hour–per–day operating conditions. The actual daily quantity may vary around this standard figure.

The Woodland District (D–3) contracts for beets in the areas of Sacramento and Solano counties and northward. There are nine contract areas and five receiving stations with about 40,000 acres or 24 percent of the total.

Planting is in the spring (February–June), with harvest occurring in the fall until rain prevents further harvest and again in the spring once the ground becomes dry enough for harvest.

The Woodland Factory (F–3) operates for approximately eight or nine months of the year. The year's operation typically starts in July, with the beets for processing coming from D–4. The harvesting of D–3 beets starts in August and, by October, D–3 supplies all of the beets for F–3. In the late fall and throughout the following spring, D–3 supplies part or all of the requirements of F–1 in addition to F–3. F–3 was erected in 1937 and has a rated capacity of 3,600 tons per day.

MODELING THE PRODUCTION–PROCESSING SYSTEM

Concepts and Definitions

Models of economic systems consist of four well–defined elements: components, variables, functional relationships, and parameters.

The *components* of the beet sugar production–processing system are the three subsystems for production, assembly, and processing. Production contains all activities involved in producing and harvesting beets. Assembly includes the activities required to move the beets from the fields to the field stations and to the processing plants. Processing transforms the beets into final products.

There are four types of variables in this system:

State variables define the state of the system at any point in time. Examples are acres available for harvest, moisture index, transit losses, and tons of beets delivered to a receiving station or to a factory.

Control variables (or decision variables) are those to which values must be assigned as part of the managerial decision process. Included are variables such as planting dates, factory starting dates, quantities to be harvested in a particular region, and quantities to be shipped from a particular region to a given factory.

Exogenous variables act on the system but are not influenced by it. Examples are weather events which may affect growth rates, yields, planting dates, or quantities harvested.

Endogenous variables are the performance measures of the system. They are generated from the interaction of the system's exogenous, control, and state variables according to the system's functional relationships. The endogenous variables in this model are annual average costs and average returns to growers, average costs of processors, combined average costs of the total system, and accumulated quantities of beets and sugar produced.

Functional relationships are the equations which describe the interaction among variables and components of the system. There are three types: behavioral equations, identities, and decision rules.

Behavioral equations are functional relationships which must be estimated empirically or determined from technical specifications. An example is a yield equation which relates the tons of beets produced per acre to variables such as planting date, average temperature during growth, and time from planting to harvest. Probability distributions of random variables, such as temperature, rainfall, and soil moisture, are also included in the set of behavioral equations.

Identities are definitions or tautological statements about the components of the model which, along with the behavioral equations, are required to generate the behavior of the system. (Examples: total production equals the sum of production by districts; ending inventory equals beginning inventory plus amount received less amount used.)

Decision rules are those by which management assigns values to the decision variables (control variables) of the system. These values may be expressed as functions of the state variables of the system. For example, the starting date for F–1 is a function of the expected tonnage to be harvested. In a number of cases, values assigned to decision variables remain constant regardless of the state of the system but may be varied among simulation runs.

Parameters are the constants of the system. There are three types. One type is the coefficients of the behavioral equations––for example, the mean and standard deviation of a probability distribution. The second type consists of constants such as shrink factors, receiving station capacities, and transportation costs. The third type results from assigning constant values to elements which, in some models, might be regarded as variables. Examples are receiving station cost per ton, hauling allowances, and harvest cost per ton in each production area. Also included are decision variables to which constant values were assigned as noted above.

How the Model Works

Our model of the sugar beet production–processing system is formulated to simulate on a computer the sequence of events and activities––and resulting costs and outputs––as they might occur in any given season. Initially, the decision rules are specified so as to

approximate the rules used in the existing (historical) system. Because of the random elements involved, a series of simulation runs is made from which are calculated averages and measures of variation of the performance variables (average costs, etc.) of the system. Rules and parameters then may be altered and the effects on the system performance observed via simulation.

For decision purposes, each year may be viewed as consisting of three distinct time periods: preplanting, planting, and harvest. These periods may overlap since planting may occur in one production area while harvest occurs in another. The preplanting period is the time before the seasonal plan becomes committed. The harvest period is separated into a dry harvest (May–September) and a wet harvest (October–April) to coincide with the normal dry and rainy periods. During the dry period, all computations are made on a semimonth basis, while during the wet season they are made daily because of the uncertain effects of weather events.[1] Following initial decisions as to time and number of acres planted in each of 35 producing areas, the model determines yields and quantities harvested during each semimonth or daily period, allocates harvest quantities to 27 receiving stations, and determines shipments from receiving stations to each of the four factories.

The calculations necessary to simulate the operations of the system are outlined in Figure 1. A more detailed diagram is given in Appendix A. The program first reads in values of constants and decision rules and calculates additional constants which may be computed from the values read in. The first year is started by generating values of all of the random variables for each semimonth or daily period for the entire year. Initial conditions and preplanting decisions are specified, and planting periods are determined for each producing area. The actual mean planting dates are determined as a function of the moisture index.

The harvest period then begins. Yields and quantities available to harvest are computed by behavioral relationships.[2] It is then necessary to determine if each factory is operating and, if not, to decide if it should start.[3] Beet requirements are computed for each factory and decisions made as to quantities harvested in each district and production area. During the wet season, these decisions are modified by values of the moisture index.

A series of identities then compute values relating to the state of the production subsystem such as acres harvested, sugar percent, accumulated tons and acres harvested, and quantities remaining to be harvested. Cultural and harvest costs are also computed.

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[1] During the dry season the weather events are highly predictable, so direct semimonth computations may be expected to give almost the same results as daily computations summed over the same period. The advantage of this is to greatly reduce the computational burden.

[2] Explained in *infra*, page 17; also, Appendix B, *infra*, page 50.

[3] See discussion of decision rules, *infra*, page 22.

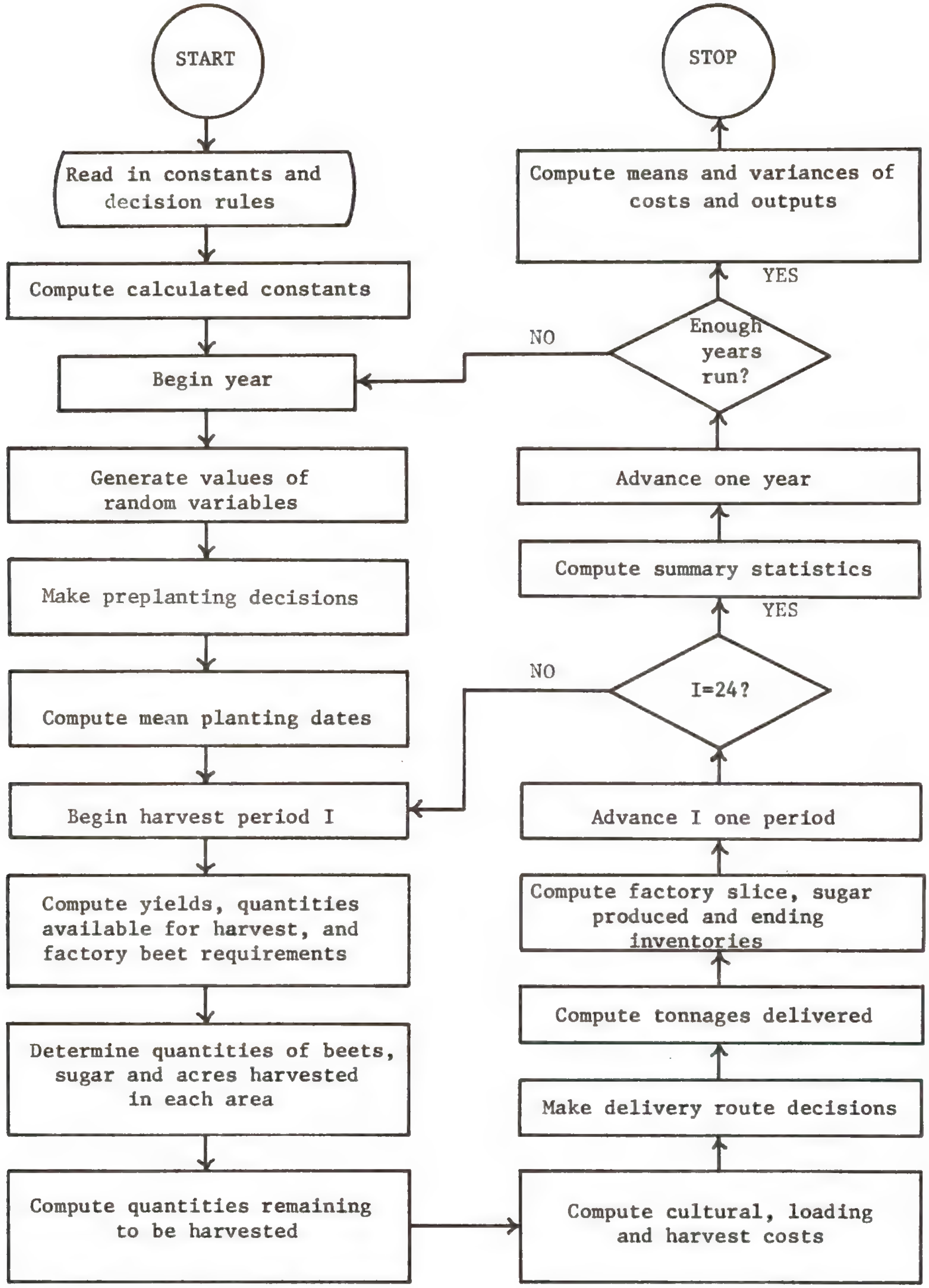

FIGURE 1. General Flow Chart

Decisions are made next as to the route and method of shipment from production areas to receiving stations and receiving stations to factories. The decision procedure is explained in the later discussion of decision rules. Another series of identities or simple technical equations then is required to compute the results of implementing these decisions, including the quantities delivered adjusting the sugar losses in transit and quantities available for processing adjusting for storage losses at the factory.

The factory slice during each period is determined by adding a randomly distributed variable to the normal quantity for the date. Another set of equations then determines the sugar in the beets sliced, total sugar produced, sugar not extracted (sugar in beets less sugar produced), and ending inventories. The model also determines whether individual days are operating days, test–out days, or lay–by days, or determines the number of such days within each semimonth period during the dry season.

This completes the computations for one period, so time is advanced to the next period and the process repeated. If the end of the season has been reached, the relevant variables are summarized to obtain seasonal quantities, costs, and returns. When all annual calculations have been completed, time is advanced one year, new random variables are generated, and another year of data obtained. When the desired number of years of simulation has been reached, operations cease; and the means and variances of the yearly values are computed.

Behavioral Relationships

The eight types of behavioral relationships involved in the model are outlined briefly below. The numbers in parentheses indicate the blocks in Appendix A where each relationship enters the computational process.

Dependent variable	*Nature of relationship*
1. Yield per acre––tons of roots and tons of sugar (Block 12).	1. Relates yields to planting dates, average high tempera–ture during growth, and time from planting to harvest.
2. Quantities available for harvest (Block 14).	2. Relates quantity available in each production area and time period to acres planted, yields, and an acreage proportion.[1]

[1] The acreage proportion is the proportion of total production area acreage considered by management to be available for harvest in each time period. It is explained more fully in the Appendix B section on quantity available for harvest.

3. Average high temperature during growth (Blocks 4 and 12).	3. Probability distribution.
4. Moisture index (Blocks 4, 6, 10, 18, and 19).	4. Probability distribution.
5. Proportion of normal harvest achieved during wet periods (Block 19).	5. Probability distribution which varies with the level of the moisture index.
6. Transit and storage losses (Blocks 37, 42, and 43).	6. Relates losses in weight and sugar content to temperature during transit and storage.
7. Tons sliced per day (Blocks 4 and 45).	7. Probability distribution.
8. Rail delays (Blocks 4 and 45).	8. Probability distribution.

The various relationships are represented both in equation and tabular form. Relationships 1, 5, and 6 also have attached to them random elements with specified probability distributions. The specific values of these relationships are given in Appendix B, along with explanations of the procedures used to estimate them. Relationship 5 is explained and given in the appendix section on decision rules.

System Parameters

In addition to the parameters of the behavioral relationships, the model includes noncost parameters which are mainly conversion factors; cost parameters which are average costs of performing the activities of the system at various levels, locations, and times; and constant values assigned to some decision or control variables. The latter is discussed in the section dealing with decision rules. The noncost and cost parameters are listed below followed by brief definitional or descriptive statements pertaining to each. The numbers in parentheses refer to the blocks in Appendix A where the constants enter the computational process, and the table references designate the appendix tables which give the values of the constants where appropriate.

The costs used are "typical" average costs for each component of the model. They were derived from records of the processor, the studies of the Agricultural Extension Service [8], and consultation with the processor fieldmen and management. Although production and cost functions were not developed, the average costs estimates vary by

area, time period, factory, and with quality and yield variations. Thus, the actual cost experience for the total system and the major subsystems is affected by the values assigned to the decision variables and the random weather events.

Noncost Parameters

1. Expected yield (Block 8, Appendix Table C–1)

   Average yield for each production area, 1965–1970.

2. Clean beet percentage (Block 32, Appendix Table C–1)

   Percent of original weight remaining after removal of dirt, leaves, and crown left on the beet after harvest and delivery, 1965–1970 average.

3. Estimated clean beet percentage (Block 17)

   Average clean percentage for all areas. Value is 92.10.

4. Conversion rate to field weight (Block 24)

   Rate of conversion from first net weight to field weight. Value is 1.03.

5. Sugar in crowns (Block 33)

   Sugar carried into the factory in the crown or stem which remains on the beet but is not counted in purchase weight. The crown adds 0.6 percentage points to the purchased sugar percent of the root.

6. Shrink factor (Block 55)

   Loss of rail tonnage due to shrink in harvest. Used to compute the rail charge the processor pays. Values are 3½ percent, July 1–January 31; 4 percent, February 1–June 30; except always 4½ percent for shipments from the Imperial Valley.

7. Extraction rates (Block 46, Appendix Table C–2)

   Conversion rate from sugar in beets sliced to sugar produced. Varies with time and factory reflecting variations in beet quality.

8. Number of days in each semimonth period (Appendix Table C–3)

   A specification of the modeling process.

Cost Parameters

A. Production

1. Cultural cost (Blocks 27 and 52, Appendix Tables C–4, C–5, and C–6)

   Typical costs of growing beets in each area. Appendix Table C–4 gives a detailed breakdown for one area; Appendix Table C–5 gives the summary estimates for each production area; and Appendix Table C–6 gives the added costs incurred due to keeping beets in the ground for a longer period––principally due to increased interest cost and the necessity of additional irrigations. Costs are expressed per acre so cost per ton varies with yield. Overhead costs, such as taxes, insurance, rent, and annual costs of equipment, buildings, and irrigation system, are not included.

2. Opportunity cost (Blocks 27 and 52, Appendix Table C–7)

   Cost that a grower may incur if his beets have not been harvested in time to plant his next crop to the most profitable alternative. Only associated with spring harvested beets. A representative figure was developed based on the difference in per acre return for tomatoes (an early spring crop) and field corn which may be planted later. The calculations given in Appendix Table C–7 provide an estimate of $40.80 per acre as the "opportunity" cost.

3. Harvest cost (Blocks 27 and 52)

   Cost grower pays for harvesting beets, including topping beets prior to harvest and loading charge of the hauler. Specified at typical commercial rates: Harvest cost (including topping) is $1.25 per ton (first net ton basis) in all areas. Loading charge is 85 cents per ton (field–weight basis) in all areas except 90 cents in Areas 25 and 30, 95 cents in Areas 26 and 33, and $1.00 in Area 35.

4. Acquisition cost (Block 52)

   Cost to processor and payment to grower for beets purchased which varies with the net selling price and sugar percent.[1] For modeling purposes N.S.P. is specified as $9.00 per cwt. of sugar. Transforming the contract provisions into equation form gives:

   Acquisition cost per ton (second net weight) =
   (4.5652 + .015 x sugar percent) x cwt. of sugar.

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[1] See *supra*, page 8.

The grower also receives an additional *conditional payment.*[1] Assuming an 87.1 percent average recovery rate (extraction rate) and a payment of 80 cents per cwt. of sugar, the conditional payment per ton (second net basis) is .27872 times the sugar percent.

5. California Beet Growers Association dues (Block 52)

   Amount grower pays to California Beet Growers Association. Collected by the processor and is currently 5 cents per ton (first net basis).

6. Grower's hauling cost (Block 52)

   Amount grower pays to have his beets transported to the receiving station or factory. Rate is 3 cents per ton (field weight) per mile. For each time period and each production area, a mileage has been specified. These values were obtained from the processor and reflect harvest in different locations within the same production area.

7. Hauling allowance (Block 52)

   Amount the processor reimburses the grower for hauling beets to the nearest receiving station. Specified at 2.5 cents per ton (first net basis) per mile. The mileage assumed is the same mileage as was used for the grower's hauling cost. If the grower hauls to a more distant station, the payment is 3.5 cents per ton per mile (first net basis) for the additional mileage. This is approximately the same as the grower cost of 3 cents per ton per mile, field–weight basis. The charges used for this overhaul were the costs supplied by the processor based upon an assumed average mileage of overhaul.

8. Dirt haul cost (Block 52)

   Charge grower pays to processor to carry away the dirt accumulated at the receiving station. Specified as 3 cents per ton (first net basis).

9. Tare lab cost (Block 55)*

   Cost to the processor for operating labs where samples of each of the beets delivered are analyzed for clean beet percentage sugar percentage.

10. Receiving station cost (Block 53, Appendix Table C–8)*

    Variable cost per ton for operating the receiving stations.

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[1] See *supra*, page 10.

11. Transportation costs, receiving stations to factories (Blocks 28 and 55, Appendix Table C–8)

Cost to processor for shipment via rail or transport truck.

12. Freight and truck unloading costs (Block 55)*

Cost to processor per ton for unloading freight cars and trucks at factory.

13. Piling and unpiling costs (Block 55)*

Cost to processor per ton at factory (actual weight basis) for additional storage at factory.

14. Processing costs (Block 55)*

Includes variable material cost per ton, variable labor cost per ton, test–out cost per day, and lay–by cost per day.

15. Coordination costs

Cost of field organization and administrative staff at processor headquarters. Regarded as constant per season and so does not affect the model computations.

(*Figures used in the analysis are not disclosed at the request of the processor; contact Spreckels Sugar Division for access to data.)

Decision Rules––Existing System

The model contains 10 types of decision or control variables––variables to which values must be assigned as part of the managerial process. They appear in Appendix A in Blocks 7, 10, 16, 18, 19, and 28. The nature of each rule is outlined briefly below. More detailed explanations and the empirical basis for the rules are given in Appendix D.

Decision variable	*Nature of rule*
Preplanting decisions	
1. Total tonnage and acreage to be contracted.	1. Based on management goal of maximum number of days of factory operation.
2. Allocation of acreage among areas.	2. Based on historical proportions.
3. Factory supply sources.	3. Specifies alternative supply sources for each factory which reflect historical practice based on consideration of transportation cost, available supplies, and factory needs.
4. Factory starting dates.	4, Fixed dates for F–2, F–3, and F–4. F–1 date established residually based on expected tonnage.
5. Standard inventory levels.	5. Based on historical management practice.
Planting period decisions	
1. Time of planting.	1. Normal planting periods specified by historical practice. Actual planting is influenced by moisture index.
Harvest period decisions	
1. Quantity of beets harvested in each district.	1. Rules vary by time period and are modified by moisture index values during the wet season. Each district supplies its local factory first, then proceeds according to factory supply source rules and priority rules.

2. Allocation of district quantities harvested in production areas.	2. Based on availability of beets in each area, capacities of receiving stations, and previously specified target completion dates and quotas.
3. Delivery routes and methods.	3. Rules are designed to minimize expected transportation cost.
4. Factory shutdown and startup dates.	4. Each factory continues to operate until rain prevents further harvest; operation is resumed in the spring when the soil again becomes dry enough for harvest.

Testing the Model

The behavioral relationships, identities, parameters, and decision rules, applied as indicated in Figure 1 and Appendix A, generate a set of measures of costs associated with the existing (observed) system. Before using this model to evaluate the effects of alternative decision rules or changes in parameter values, it is essential to verify that it is a reasonably accurate representation of the real system under study.

There are two aspects to the verification process. The first is to be sure that there are no programming or data errors. This seemingly obvious step is by no means easy since there are many calculations and stages and much data detail. The main checking procedure is to make selected hand calculations to compare with computer results and to watch for unexpectedly large or small values of the various outputs of the program. Values obtained in the printout of the computer program were also checked against original data and specifications of the model. The final model presented appears to be accurate in this respect.

The second step in the verification process is to see how well the values of performance measures generated by the model compare with observed values for the actual system under study. Cost and output measures for the latter were available to us for only one year, 1971. Since the random events of 1971 could not be reproduced exactly, the model results would not be expected to correspond exactly with the actual values. Comparison of the 1971 values with 10–year averages of costs and outputs generated by the model indicated a good degree of correspondence.[1] The deviations were small for most items

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[1] Because of the random factors involved, it is necessary to make repeated runs of the model to determine mean values of the performance measures. This also provides measures of variability (the standard deviations) from season to season. The selection of length of each computer run and the number of repeated runs involves consideration of computer cost and accuracy of results (see Zusman and Amiad [11]). Since decision strategies are developed and implemented on an annual basis, one year was selected as the length of each computer run. We arbitrarily selected 10 years as the number of years required to give reasonably accurate means and standard deviations, given the restrictions on computer funds.

and could be accounted for in terms of random variations or specific differences in 1971 conditions. Since the actual cost values were provided on a confidential basis by Spreckels, they are not presented here. The model values for the major costs and outputs for which comparisons were made are given in Table 4.[1] As a further check, the model results were discussed with members of the Spreckels staff. It was agreed that the figures generated seemed "reasonable" in the light of their experience and expectations. We thus feel satisfied that the model is a fairly good representation of the system that was observed.

EXPERIMENTATION WITH THE MODEL

Experimentation with a range of decision–rule alternatives offers a means by which the system potentially can be made more efficient. The computer model provides a basis for evaluating the effects of each rule on the system performance. For each of the many decisions, there are several alternative rules which might be applied or values which might be assigned to the control variables. The processor's objective is to choose from some feasible set the particular combination of decision rules which minimizes the expected processor assembly and operating cost. More generally, we would like to select the set of rules that minimize the total system cost, including grower opportunity costs. With many alternatives and combinations to consider, the computational burden associated with seeking such an optimum may be very large. Thus, rather than attempting to explore the complete output surface of the system, we shall show the results of using the model as a tool for improvement by making one–at–a–time changes.[2] Following this, we discuss some other changes which might be considered and the manner in which the simulations would be structured.

An Illustrative Simulation Experiment

One type of system modification that seemed potentially to offer some cost savings was to try to allocate acreage among producing areas so as to minimize total assembly cost, subject to preassigned maximum and minimum acreage values for each area. We thus formulated an alternative decision rule which would give this minimum cost result for prespecified harvest periods and harvest quantities assumed to be known with certainty. However, since the system actually operates under conditions of weather and yield uncertainty, the potential effect of the new decision rule was evaluated by running it through the simulation model. We shall first describe the nature of the decision alternative and then compare the simulated performance measures with the values obtained for the initial model.

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[1] For the complete list, see Blocks 52–55, Appendix A, *infra,* pages 48 and 49.

[2] See, for example, Zusman and Amiad [11].

TABLE 4

Ten-Year Averages of Outputs for the Model of the Existing System[a]

Variable	Units	Total	Per bag of sugar	Standard deviation
		millions		
Sugar beets				
Purchased	tons	3.807	--[b]	.221
Sliced	tons	4.138	--	.238
Sugar produced	bags	9.826	--	.607
Processors' costs	dollars			
Acquisition cost		52.064	5.299	3.371
Hauling allowance		1.633	0.166	.088
Tare lab cost		0.151	0.015	.009
Receiving station cost		0.399	0.041	.022
Transport and rail cost		5.743	0.584	.329
Rail unloading cost		0.086	0.009	.005
Truck receiving cost		0.248	0.025	.016
Variable processing cost		11.791	1.200	.623
Piling and unpiling cost		0.058	0.006	.027
Coordination cost		1.375	0.140	--
TOTAL PROCESSORS' COST		73.548	7.485	4.435
Procurement cost (Σ 1-5)		59.990	6.105	3.782
Sum receiving cost (Σ 5-7)		6.077	0.618	.344

a/ Readers interested in actual 1971 data for comparison may contact the Spreckels Sugar Division.

b/ Dashes indicate not applicable.

The total tonnage objective in the modified system is the same as for the initial model with a minor exception. During the period of the analysis, it was found that F–3 had been modernized to increase its annual capacity by 26,000 tons. In considering the decision alternative, it seemed appropriate to use this more recent tonnage figure. Expected factory slice rates thus are as given in Table 5. This increase in tonnage (from 3,862,950 in Appendix Table D–1 to 3,888,950 in Table 5) slightly distorts the evaluation of the effects of the alternative allocation rule, but the impact appears minor.

The maximum acreages for each area were estimated by representatives of the processor as the greatest quantity that the processor could expect to contract for in the area. The minimum acreages reflect the preference of the processor to maintain a certain level of production in each area. In some areas the minimum is zero. In most it is greater than zero, reflecting a commitment to growers and that beets from some sections may be of higher quality or may be available for harvest when harvest in other areas is uncertain. These maximum and minimum values are given in Table 6.

The maximum and minimum acreage values were translated into tonnage values by multiplying acreages by expected average yields for each production area. The maximum amount available to harvest during each period of the year was specified by multiplying the maximum total tonnage values by the proportions given in Appendix Table B–2. We then specified allowable harvest periods for each area as shown in Table 7. This was necessary to limit the harvest in an area to the periods beets would be available. The specification included the earliest date when harvest could start and the date when harvest had to be completed. The quantities harvested in each time period and sent to one of the four factories become the column entries of the programming problem. The number of time periods was reduced from 24 to 13, as shown in Table 7, to reduce the computational burden.

With these restrictions and specifications, the allocation problem is formulated mathematically as a linear programming problem which may be stated as follows:

$$\text{MIN TC} = \sum_{p=1}^{4} \sum_{k=1}^{35} \sum_{I=1}^{13} C_{pkI} \; X_{pkI}$$

subject to

$$\sum_{p=1}^{4} \sum_{I=1}^{13} X_{pkI} \leqslant \text{MAX k} \qquad\qquad \sum_{p=1}^{4} X_{pkI} \leqslant A_{kI}$$

TABLE 5

Expected Slice Rates by Factory and Production Period: Case I

Time period		F-1	F-2	F-3	F-4
		tons per period			
July	I	82,500	61,500	48,750	57,750
	II	88,800	65,600	52,000	61,600
August	I	83,250	61,500	48,750	57,750
	II	88,800	65,600	52,000	61,600
September	I	84,750	61,500	48,750	58,500
	II	84,750	61,500	48,750	58,500
October	I	84,750	61,500	48,750	58,500
	II	90,400	65,600	52,000	62,400
November	I	84,750	61,500	48,750	58,500
	II	56,500	61,500	48,750	58,500
December		--a/	184,500	--	117,000
Spring		249,750	228,000	186,000	213,000
May II-June II		--	--	--	163,300
Total		1,079,000	1,039,800	683,250	1,086,900
TOTAL		3,888,950			

a/ Dashes indicate no operation during that period.

TABLE 6

Acreage Restriction and Solution by Production Area

Production area	Maximum acreage	Minimum acreage	Solution acreage	Remarks
	acres			
1	2,200	1,500	2,200	Max
2	3,100	2,000	3,015	--a/
3	750	--	750	Max
4	8,000	5,000	8,000	Max
5	4,000	2,500	4,000	Max
6	4,000	3,000	4,000	Max
7	1,000	--	1,000	Max
8	17,000	10,000	17,000	Max
9	2,000	1,000	2,000	Max
10	600	--	600	Max
11	300	--	71	--
12	1,500	500	500	Min
13	3,200	2,800	3,200	Max
14	4,000	3,500	3,500	Min
15	6,200	2,000	6,200	Max
16	1,900	500	1,900	Max
17	4,900	3,000	4,900	Max
18	4,000	3,000	4,000	Max
19	1,200	500	500	Min
20	21,000	15,000	19,289	--
21	4,100	2,000	3,194	--
22	2,500	1,000	1,000	Min
23	4,000	3,000	3,000	Min
24	2,500	2,000	2,000	Min
25	7,000	3,000	4,859	--
26	2,500	--	2,500	Max
27	8,000	6,000	8,000	Max
28	8,000	5,000	7,077	--
29	6,000	4,500	4,500	Min
30	6,000	4,000	3,576	--
31	28,000	25,000	28,000	Max
32	4,200	3,000	3,000	Min
33	5,000	--	5,000	Max
34	4,500	2,000	4,500	Max
35	14,000	--	6,970	--

a/ Dashes indicate no restriction.

TABLE 7

Matrix Formulation of Harvest by Production Area and Time Period

Production area	Time period												
	1	2	3	4	5	6	7	8	9	10	11[a]	12[b]	13[c]
1				x	x	x	x	x	x				
2					x	x	x	x	x				
3			x	x			x	x					
4				x	x	x	x	x	x				
5				x	x	x	x	x	x	x	x	x	
6				x	x	x	x	x					
7					x	x	x	x					
8					x	x	x	x	x	x	x	x	
9				x	x	x	x	x					
10						x	x	x					
11						x	x	x					
12								x	x	x		x	
13								x	x	x		x	
14								x	x	x		x	
15			x	x	x	x	x	x					
16				x	x	x							
17								x	x	x		x	
18								x	x	x		x	
19									x	x		x	
20					x	x	x	x	x	x		x	
21	x	x	x	x	x								
22							x	x	x	x			
23	x	x	x	x	x								
24	x	x	x	x									
25												x	
26	x	x	x	x	x	x	x	x	x				
27		x	x	x	x	x	x	x	x	x			
28										x	x		
29	x	x	x	x	x								
30												x	
31	x	x	x	x	x	x	x	x	x	x	x		
32	x	x	x	x	x								
33	x	x	x	x	x	x	x	x	x				
34	x	x	x	x	x	x							
35													x

a/ Time periods 11 and 12.

b/ Time periods 17 to 21; no harvest in periods 13 to 16.

c/ Time periods 22 to 24.

$$\sum_{p=1}^{4} \sum_{I=1}^{13} X_{pkI} \geqslant \text{MIN } k \qquad \sum_{k=1}^{35} X_{pkI} = F_{pI}$$

$$\sum_{p=1}^{4} X_{pkI} \leqslant R_{kI} \qquad X_{pkI} \geqslant 0$$

where

TC = transport cost per season

C_{pkI} = transport cost per ton from area k to factory p in period I

X_{pkI} = tonnage harvested and shipped from area k to factory p

MAX k = maximum tonnage in area k

MIN k = minimum tonnage in area k

R_{kI} = receiving station capacity, in area k

A_{kI} = amount available, area k, in period I

and

F_{pI} = requirements of factory p in period I.

This problem is solved to obtain the transport cost–minimizing allocations of tonnage harvested and shipped from each area which is then translated back to total acreage values by summing and dividing by expected yields in each area. The allocations obtained by utilizing the factory requirements given in Table 5 are presented in Table 6. The results show that the majority of the acreages in the production areas are restricted by either the maximum or minimum allowable acreages as indicated in the remarks column. This suggests that the processor might want to reevaluate the minimum allowable acreages in areas where the minimum is restrictive.

Since these decision rules (allocations) are based on prespecified harvest periods and harvest quantities assumed to be determined with certainty, they are not necessarily optimal under conditions of weather and yield uncertainty. To evaluate the rules under conditions of uncertainty, we must run them through the simulation model.

Simulation Results

Tables 8 and 9 summarize the key measures of system performance for the model of the existing system and for the system involving the slightly increased total tonnage goal and the alternative rules for allocating acreage to production areas. The year–by–year and 10–year average differences between the two systems are given in Table 10.

Surprisingly, although the target tonnage is slightly higher for the alternative system, the realized tonnage and acreage actually decrease a bit. By district, D–1 and D–2 show some increase and D–3 and D–4 a decrease. The reason for the net reduction is a divergence between the assumed yield used in designing the alternative decision rule (constant for all time periods) and the simulated yield which varied through time and was subject to random influences.

Table 10 shows that the average grower return has increased by about 3 cents per ton (purchase weight) for a total gain to growers of about $114,000 per year. Year–by–year comparisons show that grower net returns increased during each of the 10 years simulated, so the increase appears significant. The higher net return is a result of both an increase in payment by the processor and decreased variable costs to growers. The higher processor payment to growers comes about because of existing contract provisions which tend to favor growers in the higher quality beet areas toward which acreage has shifted slightly. Growers. variable costs decreased mainly because acreage shifts away from areas of high irrigation water costs.

The new allocation rule also results in some significant reductions in processor costs. The main reduction is in receiving (primarily transportation) costs which, on the average, are reduced by 5.3 cents per ton on a field–weight basis, or a total of $217,300. This is offset slightly by increases in hauling allowance and piling costs. The final processor cost reduction is 2.07 cents per bag, or approximately $202,860, on a volume of 9.8 million bags. Again, examining the year–by–year comparisons indicates that the reduction is significant. These savings must be balanced against a reduction of 71,000 bags of sugar produced. If we assume (very roughly) a profit of 40 cents per bag, the net gain to the processor is $202,860 less $28,400, or $174,460. The combined increase in average returns to growers and the processor amounts to about $290,000 per year.[1]

It is possible, of course, that there are considerations not known to us which would make the processor reluctant to adopt these alternate allocation rules. Even so, the model reveals clearly the opportunity cost involved if there are, in fact, other things to consider.

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[1] The average acreage with the improved system is also reduced slightly (about 1,000 acres). If the returns from alternative crops were less than for beets, we would need to subtract the foregone profits from the estimated improvement in grower returns. We did not attempt to compute such a figure.

TABLE 8

Simulated Performance of the Model of the Existing System

Year	Producers					Processors				
		Average								
	Sugar beets harvested[a/]	Yield	Growers' gross return	Growers' variable cost	Growers' net return	Sugar beets sliced at factories[b/]	Sugar produced	Sum of receiving cost	Variable processing cost	All processors' cost
	million tons	tons per acre	dollars per ton harvested			million tons	million bags	dollars per ton sliced		dollars per cwt. of sugar
1	4.074	23.31	16.11	10.56	5.55	4.415	10.493	1.42	2.79	7.4511
2	3.786	21.66	16.19	11.29	4.90	4.138	9.834	1.48	2.87	7.4845
3	3.591	20.55	15.91	11.77	4.14	3.877	9.235	1.47	2.83	7.4594
4	3.903	22.33	16.31	10.97	5.34	4.267	10.218	1.51	2.83	7.4542
5	3.503	20.04	15.88	11.97	3.91	3.864	8.948	1.46	2.79	7.4814
6	3.556	20.34	15.96	11.82	4.14	3.810	9.123	1.57	2.91	7.5307
7	3.984	22.79	16.18	10.76	5.42	4.337	10.382	1.52	2.87	7.4624
8	3.633	20.78	16.09	11.50	4.59	3.967	9.345	1.47	2.87	7.5230
9	4.057	23.21	16.17	10.58	5.59	4.395	10.452	1.48	2.83	7.5018
10	3.985	22.80	16.12	10.70	5.42	4.314	10.283	1.44	2.84	7.5036
Mean	3.807	21.78	16.09	11.19	4.90	4.138	9.826	1.482	2.845	7.48521
Standard deviation	.221	1.26	.14	.55	.66	.238	.607	.04	.04	.02874

a/ Purchase weight.

b/ Actual weight (includes crowns and stems processed).

TABLE 9

Simulated Performance of the Model of the Improved System

Year	Producers					Processors				
	Sugar beets harvested a/	Average				Sugar beets sliced at factories b/	Sugar produced	Sum of receiving cost	Variable processing cost	All processors' cost
		Yield	Growers' gross return	Growers' variable cost	Growers' net return					
	million tons	tons per acre	dollars per ton harvested			million tons	million bags	dollars per ton sliced		dollars per cwt. of sugar
1	4.045	23.28	16.13	10.54	5.59	4.383	10.414	1.36	2.80	7.4306
2	3.761	21.64	16.22	11.27	4.95	4.111	9.790	1.42	2.88	7.4560
3	3.559	20.48	15.93	11.76	4.17	3.927	9.166	1.43	2.82	7.4361
4	3.866	22.24	16.31	10.96	5.35	4.225	10.114	1.46	2.82	7.4361
5	3.475	20.00	15.89	11.94	3.95	3.833	8.880	1.44	2.79	7.4743
6	3.532	20.32	15.97	11.79	4.18	3.885	9.064	1.50	2.86	7.5203
7	3.952	22.74	16.18	10.74	5.44	4.234	10.283	1.46	2.88	7.4288
8	3.601	20.72	16.10	11.48	4.62	3.915	9.277	1.42	2.88	7.4909
9	4.041	23.25	16.18	10.54	5.64	4.378	10.397	1.42	2.83	7.4867
10	3.962	22.80	16.12	10.69	5.43	4.289	10.163	1.38	2.84	7.4858
Mean	3.779	21.75	16.10	11.17	4.93	4.118	9.755	1.429	2.840	7.4645
Standard deviation	.222	1.28	.13	.55	.65	.212	.600	.04	.03	.03156

a/ Purchase weight.

b/ Actual weight (includes crowns and stems processed).

TABLE 10

Differences in Performance of the Models of the Existing and Improved System a/

Year	Producers					Processors				
		Average								
	Sugar beets harvested b/	Yield	Growers' gross return	Growers' variable cost	Growers' net return	Sugar beets sliced at factories c/	Sugar produced	Sum of receiving cost	Variable processing cost	All processors' cost
	million tons	tons per acre	dollars per ton harvested			million tons	million bags	dollars per ton sliced		dollars per cwt. of sugar
1	-.029	-.03	+.02	-.02	+.04	-.032	-.079	-.06	+.01	-.0205
2	-.025	-.02	+.03	-.02	+.05	-.027	-.044	-.06	+.01	-.0285
3	-.032	-.07	+.02	-.01	+.03	+.050	-.069	-.04	-.01	-.0233
4	-.037	-.09	-- d/	-.01	+.01	-.042	-.104	-.05	-.01	-.0181
5	-.028	-.04	+.01	-.03	+.04	-.031	-.068	-.02	--	-.0071
6	-.024	-.02	+.01	-.03	+.04	+.075	-.059	-.07	-.05	-.0104
7	-.032	-.05	--	-.02	+.02	-.103	-.099	-.06	+.01	-.0336
8	-.032	-.06	+.01	-.02	+.03	-.052	-.068	-.05	+.01	-.0321
9	-.016	+.04	+.01	-.04	+.05	-.017	-.055	-.06	--	-.0151
10	-.023	--	--	-.01	+.01	-.025	-.070	-.06	--	-.0178
Mean	-.028	-.03	+.01	-.02	+.03	-.020	-.070	-.053	-.005	-.0207

a/ Differences are improved minus existing system value.

b/ Purchase weight.

c/ Actual weight (includes crowns and stems processed).

d/ Dashes indicate zero.

Other Experiments

Exploration of other decision rule alternatives and systems changes may reveal additional possibilities for improvement. Although we would expect the potential gains to be modest in percentage terms, they may be significant in absolute amounts and seem likely to be large in total relative to the cost of formulating and using this type of simulation model. Several other potential experiments are discussed below. We have not carried out the actual computations since our goal is not primarily one of redesigning this particular system but rather to stimulate the thinking of managers and economic analysts concerning the potential value and uses of this type of system modeling.

Tonnage and Acreage Decisions

Given the objective of producing maximum sugar (under current conditions) and faced with possible restrictions on production in future periods, management planning clearly would be enhanced by measures of the likely cost effects of decreases in production or efforts to increase production. Such measures may be obtained by varying the values assigned to total tonnage and the associated values of total acreage and acreage allocated to each production area. Such changes must, of course, be consistent with factory and harvest capacities.

To illustrate how this might be modeled, consider the following alternative situations.

Case I. Suppose that modifications of F–3 permit an increase in slice of 26,000 tons of beets during the period July–November. Appendix Table D–1 values then might be modified as in Table 5, with the F–3 column changed. As noted previously, this modification was, in fact, considered and implemented during the period of the analysis.

Case II. Production is to be reduced by 534,800 tons with F–3 quantities still specified as in Table 5 and the reduction in tonnage coming from F–1. The expected slice rates by factories and time periods thus might be as in Table 11. This reduction was selected to make F–1 self–sufficient on beets harvested in D–1. This would eliminate the costly transportation charges incurred when other districts ship to F–1.

Given these situations and specified expected slice rates, the acreage required would be 173,801 for Case I and 148,772 for Case II. These acreages then must be allocated to production areas. The proportions specified for the existing model could be used (Appendix Table B–2) or, perhaps more efficiently, the alternative method that minimizes expected assembly costs of the processor subject to maximum and minimum acreage restrictions for each area.

TABLE 11

Expected Slice Rates by Factory and Production Period: Case II

Time period		F-1	F-2	F-3	F-4
		tons per period			
July	I	--[a]	61,500	48,750	57,750
	II	--	65,600	52,000	61,600
August	I	--	61,500	48,750	57,750
	II	88,800	65,600	52,000	61,600
September	I	84,750	61,500	48,750	58,500
	II	84,750	61,500	48,750	58,500
October	I	84,750	61,500	48,750	58,500
	II	90,400	65,600	52,000	62,400
November	I	84,750	61,500	48,750	58,500
	II	--	61,500	48,750	58,500
December		--	184,500	--	117,000
Spring		--	228,000	186,000	213,000
May II-June II		--	--	--	163,300
Total		518,200	1,039,800	683,250	1,086,900
TOTAL			3,328,150		

a/ Dashes indicate not in operation.

Factory Supply Sources

The supply sources for each factory for the existing system are specified in Appendix Table D–3. Many of these specifications are not subject to meaningful change. However, there are some possible variations that might be considered, such as shifting the date when D–3 replaced D–4 as the district which supplies any quantity that D–1 is unable to provide for F–1. Changes in Appendix Table D–3 would affect harvest period decisions also as indicated in the discussion of the existing system decision rules.

Factory Starting Date Decisions

Opportunities for varying this decision variable are also somewhat limited, but it might be of interest to consider the effect of having F–1 start when the amount available to harvest in D–1 equals or exceeds the harvest level required for the operation of F–1. This would replace the more complex decision rule outlined for the existing system.

Standard Inventory Levels

The standard factory beet inventory levels specified for each period were determined in the initial model on the basis of historical practice. It would be of interest to see how variations in levels at different times might affect operating costs. These variations would be aimed at reducing sugar losses during some period or, by increasing levels in the winter, extending the period of factory operations.

Planting Dates

The method of assigning planting dates in the initial model was based on empirical estimates that determined mean planting dates as a function of the value of the moisture index. By using these critical levels, but varying the earliest date that the mean planting date could occur, changes in the normal planting periods could be assessed.

Quantity Harvested in Each District

The existing decision rules reflect the management policy that requires D–2 and D–3 to complete harvest at about the same time. The opportunity of this policy might be evaluated by replacing the rule specified for May–June with the rule specified for July–September.[1]

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[1] For rules for the existing systems, see Appendix D, *infra*, page 77.

Quantity Harvested in Each Production Area in Each Time Period

When the total acreage and allocation of acreage to production area changes, it is desirable to make the associated changes in the decision parameters which determine the quantity harvested in each production area in each time period. For example, in the illustrative simulation experiment, changes were made in the proportions listed in Appendix Table D–9 as well as reducing the quantity of two D–4 areas previously operating at receiving station capacity. Options for considering changes in the quantities harvested in D–1, D–2, and D–3 during the fall are limited to changes in the quantity available for harvest. The consequences of attempts of earlier harvest in these areas could be evaluated by the model.

Delivery Routes

The model could be utilized to evaluate the effects of constructing new receiving stations or alternatively closing existing stations (or any combination thereof). New costs estimates would have to be established for grower's hauling costs, hauling allowance, and transit costs from the receiving station to the factories.

Factory Operation

It would be of interest to consider the effects on cost of shifting the first allowable date for closing down factories from November II (I = 10) to December I (I = 11) and moving the start–up date of F–1 from March II to March I, thus adding to the potential of operation. This may be done by respecifying the allowable date that F–1 can open in the spring (a control variable in the program).

Changes in Parameters

Although the parameters of the model are not directly controllable in the sense of decision variables, management may find it useful to assess the potential effects of changes in some of these constants. For example, changes in expected yields may affect acreage and allocation decisions, and changes in transportation costs may affect delivery routes and methods, with resulting alterations in the total system cost. Answers to questions concerning such parameter changes may be obtained readily by simply changing the constants of interest in the model. The computer then generates the measures of system performance. Since computer time is not free, the purposes and form of such parameter explorations should, of course, be considered carefully in advance.

SUMMARY AND CONCLUSIONS

With advancing technology and continuing industrialization of agriculture, the separate producing and marketing systems for many agricultural commodities, once coordinated almost entirely by prices, have evolved increasingly into sets of integrated systems for purposes of output determination and scheduling of activities. Growers, processors, and consumers all have an interest in the way these systems operate, for the methods of coordination affect returns to growers, costs of processors, and, ultimately, prices paid by consumers. Because of the interrelated activities involved and the many weather and biological uncertainties, it is often very difficult to evaluate the expected consequences of alternative coordination decision rules that might be adopted. One means of aiding the decision process is to construct a model that simulates the behavior of the system under uncertainty and to use the model, via computer, to evaluate the effects of different decision rules or changes in the system. This study develops such a model for a sugar beet production–processing system consisting of about 1,000 growers and a single processor with four plants.

Nature of the Model

The model consists of a set of equations which determines the state of the system at each discrete point in time as functions of previous states, random weather and biological factors, and the values assigned to decision variables controlled by management, such as acres to be planted or harvested. The state of the system is measured by variables, such as acres available to harvest, acres actually harvested, yield, and tons delivered to factories. Costs and returns to growers and processors, which are the primary measures of system performance, are determined by values of the state variables.

The model operates by first establishing rules which determine the values assigned to decision variables. These may be expressed as functions of the state of the system or, in some cases, as predetermined constants. These rules and constants, along with other constants such as extraction factors and transport costs, are read into the computer. The state of the system for the first period (first half of July) is determined by the preplanting and planting decisions and by setting initial values of other state variables, such as beet inventories, at zero. Values are generated for weather events and other random variables. Yields and quantities available for harvest are determined by functional relationships, and the quantities harvested are determined by the harvest period decision rules and weather conditions. Other decision rules, behavioral relationships, and identities then determine shipment patterns, the quantities of beets sliced, and the sugar produced. The computer advances time to the next period and continues these calculations sequentially for each period until rain forces termination of the harvest. Operations are resumed again in the spring, according to the factory start–up rules, and continue until harvest in all areas has been completed which occurs by July 1. Accumulated cost and output values are then computed for the year.

Because of the random elements involved, each year is different. Average values of costs, returns and outputs and measures of variation are obtained by making repeated simulation runs for each decision situation.

The model was tested by comparing reported cost values with simulated values determined under generally similar conditions and by consulting with processor personnel concerning the "reasonableness" of the results. We concluded that the initial model was, in fact, a reasonable representation of the real system modeled.

Uses of the Model

The principal value of the model is that it permits us to evaluate effects of changes in the system in a dynamic and uncertain framework without actually disturbing the system itself. Decision rules are the most easily altered part of the system since they are directly controlled by management. Since the model includes 10 types of decisions, each with several alternative rules which plausibly might be considered, the potential number of variations is very large. Because of the considerable amount of computer time involved, we did not attempt to evaluate all of these possibilities. Instead, we selected one alternative that seemed particularly promising to illustrate the experimental procedure and the outcome and then suggested one or two alternative formulations for each type of decision.

The alternative decision rule considered pertains to the method of allocating acreage contracted among producing areas. The new rule was derived by using linear programming to minimize expected transportation costs to factories, subject to maximum and minimum acreage limitations in each production area. Harvest patterns were assumed to be known with certainty. The alternate decision rule then was evaluated under uncertain conditions by the simulation procedure.

Comparing results with the original model suggested potential increases in returns to growers averaging $114,000 per year and a reduction in processor costs averaging about $203,000 per year. Since production was slightly reduced, it was necessary to deduct potential profit losses of about $28,000 for the processor from these values, leaving a potential average net gain of about $290,000 per year. Year–to–year comparisons suggest these average gains were not a chance result.

Other potential uses of the model are to (1) evaluate the effect of changes in system parameters, (2) consider cost effects of organizational changes, such as adding another factory or closing an existing one, and (3) evaluate the value of additional information that might be obtained (at a cost) concerning some of the random elements affecting the system.

Parameter changes, such as variations in transportation cost, may be evaluated by simply changing the constants of interest and then letting the computer generate new values of system–operating costs and output.

Consideration of organizational changes would require a few modifications and some reprogramming, but this would not be difficult. This type of modification would also provide a means of evaluating alternative factory locations.

It may be possible, at some cost, to obtain improved predictions of yields or even weather during particular years. In such cases alternative strategies or decision rules may lead to better outcomes than suggested for the case where only the prior probabilities are available. The model provides a means of generating the data needed to evaluate the value of such additional information and to suggest improved strategies.

With modifications to fit specific local environments, the model may be adapted readily to the analysis of other sugar beet systems.

Suggestions for Further Analysis

Although the model appears to be a good representation of the actual system, there are some ways in which it might be refined or improved. First, with more detailed data it would be possible to improve the yield relationships. It would be desirable to have yield data for smaller areas with information on fertilizer, spraying and irrigation practices, soil characteristics, and more precisely defined planting and harvest dates. If successfully incorporated into the yield equations, this would permit a more accurate evaluation of the potential effects of overwintering and variations in planting and harvest dates which perhaps could lead to improved harvest rules.

Another desirable extension would be some disaggregation of the grower component. The present model treats growers as a group in each area. If data pertaining to individual farms could be obtained and included in the model, the distribution of effects of alternative decision rules and policies could be more readily evaluated. Of course, this would also increase the complexity and number of computations required but probably would be well worth the added computer time.

Conclusions

Our experience in formulating and experimenting with this model leads finally to three conclusions which we believe to be quite significant. First, the present real system seems relatively efficient. Our experiments with the model did not and likely would not uncover any possibilities for spectacular improvements. Nor did we observe any

organizational characteristics which, if changed, are likely to lead to large reductions in cost. In this sense, we conclude that the existing system is functioning very well.

On the other hand, the study did reveal the possibility of achieving some modest gains. Our second conclusion is that development of this type of modeling by the processor or by industry groups would offer a potentially very high return on investment. A research expenditure of perhaps $20,000 to $40,000 the first year and probably less later could easily uncover possible costs savings of several times that amount. Most investors would be exceedingly pleased with such returns.

Finally, we feel the development of this type of model would be a very useful exercise for the staff of many processing firms. The act of formulating and using the model forces a degree of rigor into thought processes that can provide greater insight into the nature of the operations. The systems thinking required and the interaction of the analyst with imaginative management seem likely to stimulate ideas that go well beyond the initial modeling requirements. Although these intangible values are difficult to measure, they may very well exceed the more directly quantified benefits.

APPENDIX A

Sequence of Computer Calculations

APPENDIX A

Sequence of Calculations Required to Simulate the Beet Sugar Production-Processing System

(1) *READ*

(a) Values of constants
(b) Decision rules

(2) Compute calculated constants

(3) Begin first year (year = 1)

(4) *GENERATE VALUES OF RANDOM VARIABLES*
(For each production area, period, or factory)

(a) Average high temperature during growth
(b) Change in moisture index
(c) Tons sliced
(d) Rail delays
(e) Random components of yield equation
(f) Random components for quantity harvested equation

(5) *SET INITIAL CONDITIONS*

(a) Moisture index = 0
(b) Acreage available for harvest = 0
(c) Factory beet inventories = 0
(d) Seasonal totals = 0
(e) Computational variables = 0

(6) Compute moisture index for each day and district

(7) *MAKE PREPLANTING DECISIONS*

(a) Desired total tonnage
(b) Planned total acreage
(c) Acreage in each production area
(d) Factory supply sources
(e) Factory starting dates
(f) Standard inventory levels

(8) Compute expected tonnage in each production area (acreage x expected yield in each area)

(9) Compute final planned total tonnage (sum of expected tons in each production area)

(10) Compute mean planting dates (when 50 percent of area's acreage has been planted); depends on level of moisture index

(11) Begin harvest period (set I = 1)

(12) *COMPUTE YIELDS IN EACH AREA*

(a) Tons per acre is a function of average temperature during growth, mean planting date, time from planting to harvest, and a random element

(b) Sugar per acre is determined by the same variables as tons per acre

(13) If wet season (October-April), carry out model operations on daily basis

(14) *COMPUTE QUANTITY AVAILABLE FOR HARVEST*

(a) Quantity available for harvest in each area is a function of acres planted, yield, and an acreage coefficient[1/]

(b) Quantity available for harvest in each district is the summation of the quantities available for harvest for production areas in each district

(15) Transfer ending factory inventory values to beginning inventory values (tonnage and sugar)

(16) Evaluate decision to start processing if factory is not operating (see discussion of decision rules)

(17) *COMPUTE BEET REQUIREMENTS FOR EACH FACTORY*
(Set at zero if factory not operating)

A. Dry season (May-September)

Quantity needed during each semimonth period is expected slice plus adjustment needed because of changes in standard inventory level

B. Wet season (October-April)

Same as dry season except on daily basis

APPENDIX A--continued.

(18) *COMPUTE QUANTITIES HARVESTED IN EACH DISTRICT*

A. Dry period

<u>Decide</u> on quantities harvested in semimonth period; amounts determined by factory requirements and amounts available for harvest in each district (see explanation of decision rules)

B. Wet period

Quantities determined daily as a function of moisture index and normal factory requirements

(19) *COMPUTE QUANTITIES HARVESTED IN EACH PRODUCTION AREA*

A. Dry period

<u>Decide</u> on quantities to be harvested in semimonth period; amounts determined by quantities available for harvest in the production area, receiving station capacity, expected harvest completion dates, and allocation quotas (see explanation of decision rules)

B. Wet period

Determine daily quantities harvested in area as a function of daily quantity harvested in the district and allocation rules which vary with the level of moisture index

(20) *COMPUTE ACRES HARVESTED IN EACH PRODUCTION AREA*

Divide quantity harvested by current semimonth period yield

(21) *COMPUTE SUGAR PERCENT FOR BEETS HARVESTED IN EACH PRODUCTION AREA*

Divide sugar produced per acre by tons per acre (from step 12)

(22) *COMPUTE ACCUMULATED TONS HARVESTED IN EACH PRODUCTION AREA*

Sum all quantities harvested up to and including the current period or day

(23) *COMPUTE ACCUMULATED ACRES HARVESTED IN EACH PRODUCTION AREA*

Sum all acres harvested up to and including the current period or day

(24) *CONVERT TONNAGE HARVESTED TO FIRST NET AND FIELD WEIGHT BASIS*

(a) First net weight (multiply purchase [second net] weight by constant clean percentage for each area)

(b) Field weight (multiply first net weight by a constant)

(25) *COMPUTE QUANTITIES REMAINING TO BE HARVESTED IN EACH PRODUCTION AREA*

(a) Remaining acreage to harvest in each production area (acres planted less accumulated acres harvested)

(b) Remaining tonnage to harvest in each production area (remaining acreage x current yield)

(26) *COMPUTE QUANTITIES REMAINING TO BE HARVESTED IN EACH DISTRICT*

(a) Remaining acreage to harvest in each district (sum of remaining acreage for production areas in each district)

(b) Remaining tonnage to harvest in each district (sum of remaining tonnage for production areas in each district)

(27) *COMPUTE TOTAL COST BY PRODUCTION AREA AT END OF SEMIMONTH PERIOD*

(a) Cultural cost (including opportunity cost; constant for each time period x number of acres harvested)

(b) Loading and harvest cost (linear function of tons harvested)

(28) *MAKE DELIVERY ROUTE DECISIONS*

(a) Quantity shipped from production area to receiving station

(b) Quantity shipped from receiving station and method of delivery (grower truck, rail, or transports; see explanation of decision rules)

(29) If wet season (October-April), carry out model operations on a daily basis,2/ with the daily activities being summarized at the end of the semimonth period

APPENDIX A--continued.

(30) *COMPUTE TOTAL TONNAGE DELIVERED TO EACH RECEIVING STATION*

Sum of tons delivered from each production area

↓

(31) *COMPUTE SUGAR PERCENT OF DELIVERIES TO EACH RECEIVING STATION*

Weighted average of sugar percentages of deliveries to each receiving station

↓

(32) *COMPUTE CLEAN PERCENT OF DELIVERIES TO EACH RECEIVING STATION*

Weighted average of clean percentages of production areas delivering to each receiving station

↓

(33) *CALCULATE SUGAR PER TON OF BEETS DELIVERED TO RECEIVING STATION*

Sugar percentages adjusted for sugar in crowns and converted to cwt. of sugar per ton of beets (first net basis)

↓

(34) *COMPUTE TONNAGE SHIPPED BY RAIL, GROWER TRUCK, AND TRANSPORT TO EACH FACTORY (PURCHASE WEIGHT)*

Sum deliveries from each receiving station

↓

(35) *COMPUTE TONNAGE SHIPPED BY RAIL, GROWER TRUCK, AND TRANSPORT TO EACH FACTORY (FIRST NET WEIGHT)*

Sum deliveries from each receiving station

↓

(36) *COMPUTE SUGAR EQUIVALENT AT TIME OF HARVEST*

Sum of multiplication of tonnage of beets (first net basis) x sugar per ton; used to calculate sugar losses during transit

↓

(37) *COMPUTE QUANTITIES (TONNAGE AND SUGAR) DELIVERED TO EACH FACTORY ADJUSTED FOR TRANSIT LOSSES FOR RAIL, GROWER TRUCK, AND TRANSPORTS (ACTUAL WEIGHT)*

Transit losses per ton vary with average temperature in each time period

(38) *COMPUTE TOTAL DELIVERIES BY TRUCK TO EACH FACTORY*

Sum of grower truck and transport deliveries; needed to compute cost of truck unloading

↓

(39) *COMPUTE TOTAL QUANTITY DELIVERED TO EACH FACTORY (TONNAGE AND SUGAR)*

Sum of grower truck, rail, and transport deliveries

↓

(40) *COMPUTE QUANTITIES AVAILABLE FOR PROCESSING AT EACH FACTORY (TONNAGE AND SUGAR)*

Inventory carry-over plus quantities received

↓

(41) *COMPUTE SUGAR LOST IN TRANSIT*

Summary of deliveries to each factory (sugar equivalent at harvest less sugar in beets delivered)

↓

(42) *COMPUTE TONNAGE LOST AT FACTORY WHILE IN STORAGE*

Tonnage in inventory (accumulated) x tonnage lost per ton (varies with average temperature in each time period)

↓

(43) *COMPUTE SUGAR LOST AT FACTORY WHILE IN STORAGE*

Sugar in inventory (accumulated) x sugar lost per ton (varies with average temperature in each time period)

↓

(44) *COMPUTE QUANTITIES (TONNAGE AND SUGAR) AVAILABLE FOR PROCESSING AFTER STORAGE LOSSES AT EACH FACTORY*

Subtract storage losses from quantities available for processing

↓

(45) *CALCULATE QUANTITY SLICED AT EACH FACTORY*

Normal quantities for the period + a random variate - rail delays[3]

APPENDIX A--continued.

(46) *COMPUTE SUGAR IN BEETS SLICED, SUGAR PRODUCED, AND NONRECOVERABLE SUGAR LOSSES AT EACH FACTORY*

Sugar produced is sugar in beets sliced x extraction rate (constant by time period)

↓

(47) *COMPUTE ENDING INVENTORIES AT EACH FACTORY (TONNAGE AND SUGAR)*

Quantity available less quantity processed

↓

(48) *DETERMINE NUMBER OF SLICE (OPERATING), TEST-OUT, AND LAY-BY DAYS IN PERIOD FOR EACH FACTORY*

Summation of counters for each activity[4/]

↓

(49) *DETERMINE QUANTITY OF BEETS PILED IN PERIOD FOR EACH FACTORY*

Summation of daily quantities not placed in storage bins

↓

(50) *ADVANCE TIME (I) ONE PERIOD*

If $I \leq 24$, return to 12

If $I > 24$, go to 51 and begin summarizing season

↓

(51) *ACCUMULATED YIELDS AND FIRST NET TONNAGES FOR EACH PRODUCTION AREA*

(a) Yield per acre (accumulated tons harvested ÷ accumulated acres harvested)

(b) Sugar harvested (sum of sugar percent ÷ by 100 x tonnage harvested in each time period)

(c) First net tonnage (sum of first net tonnages harvested in each period)

(d) Sugar percent (accumulated sugar harvested ÷ accumulated total tonnage x 100)

(e) Sugar per acre (accumulated sugar harvested ÷ accumulated acres harvested)

(52) *COMPUTE ACCUMULATED COSTS AND RETURNS FOR EACH PRODUCTION AREA*

(a) Accumulated production costs (sum of cultural and harvest costs for each period)

(b) Grower hauling cost (constant for each time period x quantity delivered; field weight)

(c) Hauling allowance (constant for each time period x quantity delivered; purchase weight)

(d) Processor acquisition cost (payment to producer and variable cost per unit, depending on sugar percent, x number of tons purchased)

(e) Government payments to producer (variable per unit payment, depending on sugar percent, x number of tons purchased)

(f) California Beet Growers Association dues (constant x accumulated first net tonnage)

(g) Dirt-haul charge (constant x accumulated first net tonnage)

(h) Total growers' cost (sum of production, grower hauling, Beet Growers Association dues, and dirt-haul charge)

(i) Total growers' return (sum of acquisition cost--grower payment--hauling allowance, and government payment)

↓

(53) *COMPUTE ACCUMULATED QUANTITY AND COSTS OF ASSEMBLY COMPONENT*

(a) Accumulated tons delivered to each receiving station (sum of quantity delivered for each time period)

(b) Accumulated receiving station cost (constant x quantity delivered to receiving station)

↓

(54) *COMPUTE ACCUMULATED QUANTITY VALUES AT END OF SEASON FOR EACH FACTORY AND TOTAL*

(a) Tons purchased
(b) Sugar purchased
(c) Tons received by rail
(d) Tons received by grower truck
(e) Tons received by transport
(f) Total tons received
(g) Sugar lost in transit
(h) Sugar lost at factory
(i) Sugar in cossettes (beets sliced)
(j) Sugar produced
(k) Nonrecoverable sugar
(l) Tons sliced
(m) Number of slice days
(n) Tons piled and unpiled
(o) Test-out days
(p) Lay-by days

APPENDIX A--continued.

(55)

COMPUTE ACCUMULATED COST VALUES AT END OF SEASON FOR EACH FACTORY AND TOTAL

(a) Total acquisition cost

(b) Total hauling allowance cost

(c) Total receiving station cost

(d) Total tare laboratory cost (constant x quantity received)

(e) Total rail cost (constant x quantity shipped x shrink factor)

(f) Total transport cost (constant x quantity shipped)

(g) Total procurement cost (sum of a to f)

(h) Total rail unloading cost (constant x quantity delivered)

(i) Total truck unloading cost (constant x quantity delivered)

(j) Total receiving cost (sum of e, f, h, and i)

(k) Total variable factory cost

  (1) Labor (constant x number of slice days)

  (2) Material (constant x quantity sliced)

  (3) Test-out (constant x number of test-out days)

  (4) Lay-by (constant x number of lay-by days)

  (5) Total processing (sum of 1 to 4)

(l) Total piling and unpiling cost (constant x total quantity)

(m) Total processing cost

(56)

ADVANCE (T) ONE YEAR

If $T \leq k$, return to 3

If $T > k$, compute means and variances

1/ If there is a carry-over of quantity available from the previous period, it is included in the current quantity available.

2/ This includes determining the daily quantity delivered to each of the factories, determining the quantity available for processing, and generating a quantity to be sliced from a distribution form with known mean and variance (if this value is less than the quantity available, the quantity sliced is taken as the amount available). Ending inventory values are computed. If the ending inventory is zero, the decision to shut down the factory is considered.

3/ When the model is on the semimonth mode, the number generated is the average daily slice for the period. This figure is multiplied by the number of days in the period to compute the quantity sliced in the period. To introduce the aspect of daily fluctuations in inventories, the quantity slice may be modified by the reduction in slice due to late train arrivals.

4/ Each time a factory starts, there are three "test out" or three "lay-by" days. During the dry periods, this step counts the number of operating, test-out, or lay-by days during each semimonth period. During the wet period, the model determines whether each day is an operating day, a test-out day, or a lay-by day.

APPENDIX B

Specification and Estimation of Behavioral Relationships

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Specification and Estimation of Behavioral Relationships

The material that follows describes the methods used to estimate the several behavioral relationships of the sugar beet system and presents the results obtained. The discussion also explains how these relationships enter the model operation.

Yield Relationships

Yield of sugar beets may be measured in two ways: in tons of roots per acre and in pounds of sugar per acre contained in the beets. Equations are required for both types of relationships.

Root yield, in tons per acre, was hypothesized to be a function of planting date, average high temperature during growth, length of time from planting until harvest, and a random variable associated with omitted biological, cultural, and weather factors. Planting date was the mean planting date—–the date (expressed in weeks) when 50 percent of the acreage in the production area was planted.[1] Temperature affects growth through its action on photosynthesis, respiration, and transpiration [5, Chapter 2]. Average daily high temperature during growth was used to represent this variable. The length of time from planting until harvest was the difference between harvest date and the mean planting date.

Data from the 35 production areas for 11½ years (1960 to Fall, 1971) were used to estimate the yield equations. The yield figures represent averages for all fields in a given production area. This made the estimation difficult since there were variations within areas in practices and in unobservable processes, such as fertilization, irrigation, spraying for insects, and weed control.

Initial efforts to estimate separate yield equations for each of the 35 production areas proved unsatisfactory because of limited numbers of observations and limited ranges of values for the average data for each area. An alternative and more successful procedure was to pool observations from all production areas to estimate a single equation with dummy variables added to shift the level for each area. After some exploration, the yield relationship was specified to have the following form:

---

[1] This variable is explained in more detail in the section on decision rules; see *supra,* page 22.

$$TPA_j = a_o + \sum_{j=1}^{35} a_j D_j + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$$

where

TPA_j = yield (tons per acre) in production area j

a_o = intercept

a_j, b_i = estimated coefficients

D_j = dummy variables for each production area, 1 for area j, 0 otherwise

X_1 = deviation from 1960–1970 medial planting date (weeks)

$X_2 = (X_1)^2$

X_3 = deviation from 1960–1970 average high temperature during growth (°F.)

X_4 = time from planting until harvest (weeks)

and

$X_5 = (X_4)^2$.

Least–squares regression estimates of the coefficients of this equation are given in the left side of Appendix Table B–1. Separate equations were estimated for the fall and spring ahead. All production areas are included in the fall equation (Imperial, Area 35, is grouped with fall areas), but the spring equation has a lesser number since spring harvest does not occur in all areas. In both the fall and spring equations, Area 20 is the base area, the coefficients for the dummy variables being the deviation from this area.

To illustrate the use of the equations, suppose that for production Area 1 the values of the yield influencing variables are X_1 = 2 weeks, X_2 = 4, X_3 = .5 degrees, X_4 = 38 weeks, and X_5 = 1,444. Substituting these values in the fall equations gives:

$$TPA_1 = 6.44 - .51(1) + .180(2) - .008(4) - .270(.5) + .634(38)$$
$$- .005(1{,}444) = 22.99.$$

APPENDIX TABLE B-1

Yield Regression Equations

Variable	Tons per acre relationship: Fall — Regression coefficient	Fall — T-value of coefficient	Spring — Regression coefficient	Spring — T-value of coefficient
a	6.44	(1.74)*	-59.73	(-1.57)**
D_1	- .51	(- .31)		
D_2	1.84	(1.10)		
D_3	.75	(.48)		
D_4	1.62	(.97)		
D_5	2.17	(1.49)**	1.72	(.98)
D_6	1.68	(1.15)		
D_7	.42	(.29)		
D_8	3.06	(2.11)	1.23	(.71)
D_9	-3.38	(-1.23)		
D_{10}	1.76	(1.21)		
D_{11}	.07	(.05)		
D_{12}	- .42	(- .29)	1.01	(.56)
D_{13}	-2.12	(-1.39)	- 2.65	(-1.38)**
D_{14}	.68	(.47)	- 1.92	(-1.08)
D_{15}	-1.58	(-1.09)		
D_{16}	3.72	(2.55)*	- 1.01	(- .52)
D_{17}	.20	(.14)	- .01	(.00)
D_{18}	.03	(.02)	- .04	(- .22)
D_{19}	- .41	(- .28)	- .35	(- .20)
D_{20}	0	--	0	--
D_{21}	2.96	(2.07)*		
D_{22}	-4.10	(-2.44)*		
D_{23}	2.30	(1.62)**		
D_{24}	.79	(.51)		
D_{25}	- .94	(- .62)	- .49	(- .23)
D_{26}	-2.35	(-1.52)**		
D_{27}	-6.55	(-4.02)*		
D_{28}	.01	(.00)		
D_{29}	- .09	(- .06)		
D_{30}	1.39	(.96)	2.70	(1.49)**
D_{31}	-2.92	(-1.80)*	- 2.79	(- .15)
D_{32}	- .47	(- .30)		
D_{33}	-2.53	(-1.63)**		
D_{34}	-5.90	(-3.57)*		
D_{35}	-2.14	(-1.08)		
X_1	.180	(2.67)*	.173	(.97)
X_2	- .008	(-2.41)*	- .010	(- .72)
X_3	- .270	(-3.37)*	- .487	(-2.60)*
X_4	.634	(2.97)*	3.087	(2.08)*
X_5	- .005	(-1.70)*	- .029	(-1.99)*
	R^2 = .35 d = 2.06 SE = 3.55		R^2 = .24 d = 1.62 SE = 4.11	

Variable	Gross sugar per acre relationship: Fall — Regression coefficient	Fall — T-value of coefficient	Spring — Regression coefficient	Spring — T-value of coefficient
a	2,547.76	(2.13)*	-18,658.7	(-1.51)**
D_1	465.34	(.89)		
D_2	1,143.10	(2.12)*		
D_3	1,322.87	(2.62)*		
D_4	1,057.27	(1.96)*		
D_5	843.80	(1.80)*	646.18	(1.13)
D_6	518.42	(1.11)		
D_7	369.56	(.79)		
D_8	1,307.14	(2.79)*	623.87	(1.09)
D_9	- 731.10	(- .82)		
D_{10}	784.94	(1.68)*		
D_{11}	255.16	(.54)		
D_{12}	94.99	(.20)	- 255.44	(- .43)
D_{13}	- 56.42	(- .11)	- 294.47	(- .47)
D_{14}	34.96	(.07)	- 587.26	(-1.02)
D_{15}	140.84	(.30)		
D_{16}	1,677.48	(3.57)*	- 419.10	(- .66)
D_{17}	368.66	(.80)	47.88	(.08)
D_{18}	138.14	(.30)	- 224.67	(- .39)
D_{19}	- 168.73	(- .36)	- 480.85	(- .84)
D_{20}	0	--	0	--
D_{21}	656.71	(1.43)**		
D_{22}	-1,191.62	(-2.20)*		
D_{23}	740.07	(1.61)**		
D_{24}	280.96	(.56)		
D_{25}	180.83	(.37)	188.60	(.27)
D_{26}	- 723.49	(-1.45)**		
D_{27}	-1,363.64	(-2.60)*		
D_{28}	- 107.80	(- .13)		
D_{29}	- 73.31	(.16)		
D_{30}	847.71	(1.81)*	919.56	(1.56)**
D_{31}	- 521.14	(-1.00)	- 437.79	(- .45)
D_{32}	- 120.30	(- .24)		
D_{33}	- 844.28	(-1.68)*		
D_{34}	-1,305.36	(-2.45)*		
D_{35}	567.87	(.89)		
X_1	36.584	(1.69)*	- 36.196	(- .62)
X_2	- 2.780	(-2.45)*	- 3.538	(- .81)
X_3	- 89.927	(-3.49)*	- 148.316	(-2.43)*
X_4	134.017	(1.95)*	949.934	(2.06)*
X_5	- 1.049	(-1.05)	- 9.819	(-2.07)*
	R^2 = .35 d = 2.16 SE = 1,143.21		R^2 = .21 d = 1.58 SE = 1,339.32	

* Statistical significance of 5 percent or better.

**Statistical significance between 5 percent and 10 percent.

NOTE: R^2 is the coefficient of multiple determination, d is the Durbin-Watson statistic, and SE is the standard error of estimate. Extrapolating roughly from the D-W tables, 2.06 and 2.16 are in the acceptable range and 1.62 and 1.58 are in the inconclusive range of the test for positive autocorrelation. (For example of using table, see text.)

Although these equations leave a considerable amount of yield variation unexplained, most of the main coefficients are statistically significant at the 5 percent or better level and have signs that seem consistent with our *a priori* expectations.

Similar equations were estimated using *gross sugar per acre* (pounds) as the dependent variable. They are summarized in the right–hand side of Appendix Table B–1 and are interpreted in a manner similar to the root yield equations.[1]

These equations were used in the model to generate yield variations associated with decisions as to time of planting and harvest and with random variations due to temperature and (indirectly) soil moisture conditions. In the actual simulation process, a further random variable was added to the yield values. It was generated from an assumed normal distribution with zero mean and the standard error of estimate listed for each equation.

Recent introduction of a new Virus Yellows resistant variety appears to have raised average yields above the levels indicated by our historical time series. Consultation with industry personnel suggested this increase is about 15 percent, so all yield values were increased by this factor in the model applications.[2]

Quantity Available for Harvest

The amount of beets harvested on any date in any production area is limited by the acres of beets that have reached the appropriate stage of growth. This quantity, in turn, depends on the number of acres planted, the date planted, and to some extent on weather factors, such as temperature, which may affect growth rates.

Our efforts to estimate this type of functional relationship were frustrated by incomplete measures of corresponding dates of planting and dates of availability. Consultation with the processor management suggested, however, that this would not be a serious practical limitation for modeling purposes. Because of the overriding need to keep factories operating at capacity levels, the proportions of acreage regarded by management as available for harvest in each area during each period remain fairly stable (for given general planting periods) even though planting dates may vary within the planting periods. Although the proportion of the acreage available remains constant, the quantity of the tonnage available to harvest in a period is allowed to vary from season to season as yields vary (see previous section).

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[1] Since the sugar content of beets is affected by nitrogen applications, it would have been desirable to include this as a variable in the analysis. However, we were unable to obtain sufficient time series data to permit an estimate of the effect of this factor. It thus appears as an element of the unexplained residuals.

[2] The increase in yield is based on field experiments. It was not possible to verify this figure against more recent reported commercial yields because of the limited observations and variability due to other factors affecting actual yields.

Proportions of acreage available for harvest in production areas 1–20 are given in Appendix Table B–2. These values were determined by discussions with processor management and reference to data on quantities actually harvested. The figures show, for example, that 10.2 percent of the acreage in Area 1 is regarded as available for harvest in period 4; another 13 percent becomes newly available in period 5; and so on. If all acreage available is not harvested in one period, it is added to the amount available in the next. When "remaining" is indicated in the table, all acreage remaining in the production area becomes available to harvest.

Total acreage available is determined by multiplying acres planted by these proportions. Total tonnage available for harvest is then obtained by multiplying the acreage figure by predicted yields for the production period in which harvest occurs.

In Areas 21, 23, 24, 29, 32, and 34, all beets become available to harvest in period 1. Some beets in this area might be available earlier, but period 1 (July 1) is the normal starting date. Areas 25 and 30 harvest only in the spring; beets become fully available (but subject to harvest capabilities limited by the moisture index) after period 14. Beets become available for harvest in Area 35 after period 21. For Areas 22, 26, 27, 28, 31, and 33, the quantities available to harvest are established through a different process which will be described later in the discussion of decision rules. Briefly, Areas 26, 27, and 31 become theoretically 100 percent available in period 1, 33 percent in period 2, 22 percent in period 7, and 28 percent in period 10 (Appendix Table D–9).

Temperature During Beet Growth

As noted in the discussion of yield relationships, a factor affecting yields is the temperature during the period when beets are growing. To represent this variable, we used a three–month average of daily maximum temperatures during peak growth period as measured at a nearby weather station. For most areas the appropriate three–month period is June, July, and August; but in the earlier areas it is March, April, and May.

Probability distributions of these average temperatures were developed for each production area based on historical weather records. Since our temperature observations were somewhat limited for many of the local stations, we selected two stations with fairly long weather records as base stations. This restriction also greatly reduced the number of computations. Two base stations were selected so as to have these stations located in the immediate vicinity of the production areas that have similar growth and harvest periods. The earlier harvest areas are located in the south so a station in the southern San Joaquin Valley, Wasco, was selected for the spring average. Stockton was selected as the station for northern (later harvesting) areas and summer average. Regressions then were fitted to relate temperatures in the other areas (using the shorter data series) to the temperature in the base stations. The resulting equations are given in Appendix Table B–3. The table indicates, for example, that if the average June–August

APPENDIX TABLE B-2

Proportions of Acreage That Become Available to Harvest, by Production Area and Time Period

Production area	Time period 1	2	3	4	5	6	7	8	9	10 →	Total
	proportion										
1	a/			.102	.130	.336	.254	.135	.043		1.000
2					.123	.172	.172	.190	.343		1.000
3			.219	.230	0	0	.409	.142			1.000
4				.035	.116	.188	.198	.217	.246		1.000
5				.014	.049	.069	.110	.159	Remaining b/ →		
6				.032	.149	.220	.190	.409			1.000
7					.093	.343	.365	.199			1.000
8					.008	.015	.023	.045	Remaining →		
9				.121	.421	.226	.184	.048			1.000
10						.281	.285	.434			1.000
11						.082	.155	.763			1.000
12								.104	Remaining →		
13								.017	Remaining →		
14								.022	Remaining →		
15			.180	.230	.150	.150	.145	.145			1.000
16			.140	.430	.430						1.000
17								.091	Remaining →		
18								.109	Remaining →		
19									Remaining →		
20					.039	.037	.073	.027	Remaining →		

a/ Blanks indicate no harvest.

b/ "Remaining" indicates that all the tonnage to be harvested in the production area becomes available for harvest.

APPENDIX TABLE B-3

Relation to Temperature During Beet Growth in Each Production Area to Temperature in Base Stations

Production area	Relationship[a/]	R^2
1	18.82 + .725 HITEMP (5)	.73
2	53.94 + .321 HITEMP (5)	.24
3	44.03 + .326 HITEMP (5)	.14
4	60.44 + .106 HITEMP (5)	.03
5	1.000 HITEMP (5)	--b/
6	18.40 + .807 HITEMP (5)	.89
7	-23.17 + 1.212 HITEMP (5)	.81
8	-10.11 + 1.095 HITEMP (5)	.93
9	25.36 + .752 HITEMP (5)	.86
10	1.000 HITEMP (5)	--
11	-23.17 + 1.212 HITEMP (5)	.81
12	20.91 + .787 HITEMP (5)	.60
13	4.63 + .954 HITEMP (5)	.88
14	16.70 + .840 HITEMP (5)	.82
15	16.70 + .840 HITEMP (5)	.82
16	-23.17 + 1.212 HITEMP (5)	.81
17	4.63 + .954 HITEMP (5)	.88
18	20.91 + .787 HITEMP (5)	.60
19	16.70 + .840 HITEMP (5)	.81
20	20.91 + .787 HITEMP (5)	.60
21	14.02 + .837 HITEMP (32)	.28
22	9.12 + .921 HITEMP (5)	.89
23	14.02 + .837 HITEMP (32)	.28
24	6.51 + .914 HITEMP (32)	.94
25	25.10 + .753 HITEMP (5)	.60
26	- 6.84 + 1.096 HITEMP (5)	.93
27	-76.54 + 1.855 HITEMP (5)	.84
28	27.50 + .749 HITEMP (5)	.82
29	8.12 + .881 HITEMP (32)	.87
30	25.10 + .753 HITEMP (5)	.60
31	-76.54 + 1.855 HITEMP (5)	.84
32	1.000 HITEMP (32)	--
33	10.43 + .940 HITEMP (5)	.85
34	9.24 + .945 HITEMP (5)	.77
35	41.19 + .579 HITEMP (32)	.59

a/ HITEMP (5) is the three-month average of daily high temperature during June, July, and August for Stockton (Area 5); and HITEMP (32) is the three-month average during March, April, and May for WASCO (Area 32). The dependent variable in each case is the corresponding three-month average for the area indicated.

b/ Dashes indicate not applicable.

high temperature in Stockton is 92°, the predicted average high temperature for Area 20 (Woodland weather station) is 20.91 + .787(92) = 93.3°. There are only 24 equations for the 35 areas since some areas were close to the same weather station.

To obtain the probability distributions for these temperatures, we first computed three–month averages for the two base stations for the 20–year period, 1951–1970. A normal distribution was fitted to these data, with the results given in Appendix Table B–4. The Chi–square test suggests that this is a good approximation (test statistics are well below the values for 3 degrees of freedom at the 5 percent level of significance). Using these normal distributions, random temperature values were first generated for the Stockton and Wasco areas. These random values were then inserted in the Appendix Table B–3 equations to obtain temperatures for each of the production areas for each year simulated.

APPENDIX TABLE B-4

Normal Approximation to the Distribution of Average Maximum Temperature During Beet Growth, °F.

Time	Station	Mean	Standard deviation	Test to fit to normal random distribution	
				X^2	X^2 .05, 3 d. f.
Spring	Wasco	76.0	2.24	0.67	11.07
Summer	Stockton	91.6	2.28	0.98	11.07

Moisture Index

Soil moisture affects both planting and harvest operations. As it increases beyond certain levels, it becomes difficult and finally impossible for trucks and tractors to get into the fields.

The level of soil moisture is measured as a daily accumulative index which starts at zero and then adds the daily rainfall and subtracts the pan evaporation (in inches). When the index reaches a value of 2, the soil is regarded as saturated for purposes of this analysis.

Records of daily rainfall and evaporation were obtained from five weather stations in the production regions of concern. These were Davis, Manteca, Los Banos, Kettleman City, and Soledad. The number of observations was limited for some of these stations, so Davis, with the longest records, was selected as a base area from which to compute moisture values in the other areas. The procedure followed was the same as for the variable temperature during growth––fitting regression equations to data for shorter periods to obtain relationships between soil moisture values at Davis (the base area) and each of the other stations. The results are given in Appendix Table B–5. These relationships were estimated using daily observations (grouped by month) for the 1965–1970 seasons for Manteca, Los Banos, and Kettleman City and the 1966–1970 seasons for Soledad.

The equations take the form:

$$Y = a + b_1X_1 + b_2X_2$$

where

Y = moisture index in area on given day

X_1 = moisture index in Davis on given day

X_2 = moisture index in area on previous day

a = intercept

and

b_i = regression coefficient.

To illustrate the use of the equations, if the moisture index at the Davis station is 0.2 on November 2 and had been 0.1 at Manteca on November 1, the predicted moisture index for Manteca on November 2 is

$$.07 + .62(0.2) + .96(0.1) = .28.$$

The reason for including the previous day's value of the moisture index for the region is to allow for carry–over effects from day to day. The Manteca values apply to the producing areas in D–2, Los Banos to Areas 25 and 30, Kettleman City to the other areas in D–4, Soledad to the areas in D–1, and Davis to the areas in D–3.

APPENDIX TABLE B-5

Relation of Moisture Index Values in Selected Stations to Soil Moisture at Davis

Month	Manteca Relationship[a/]	R^2	SE[b/]	Los Banos Relationship	R^2	SE[b/]
October	$.02 + .51X_1 + .92X_2$ (3.93) (7.05)	.76	.10	$.02 + .29X_1 + .91X_2$ (2.20) (6.86)	.75	.10
November	$.07 + .62X_1 + .96X_2$ (10.34) (37.59)	.92	.16	$.05 + .07X_1 + .97X_2$ (.84) (28.62)	.87	.23
December	$.01 + .48X_1 + .99X_2$ (12.61) (121.42)	.99	.07	$.05 + .09X_1 + .97X_2$ (1.06) (59.87)	.96	.15
January	$.05 + .43X_1 + .97X_2$ (11.00) (58.34)	.95	.11	$.04 + .13X_1 + .97X_2$ (1.27) (9.67)	.94	.15
February	$-.05 + .39X_1 + 1.02X_2$ (15.31) (121.06)	.99	.04	$-.02 + .34X_1 + 1.00X_2$ (6.96) (104.97)	.99	.08
March	$.02 + .60X_1 + .98X_2$ (12.29) (51.82)	.96	.12	$.01 + .17X_1 + .91X_2$ (5.11) (49.67)	.96	.08
April	$.10 + .48X_1 + .83X_2$ (4.18) (9.39)	.71	.15	$.07 + .17X_1 + .48X_2$ (1.52) (2.83)	.19	.15

Month	Kettleman City Relationship	R^2	SE	Soledad Relationship	R^2	SE
October	$.06 - .08X_1 + .76X_2$ (-.33) (3.02)	.37	.22	$.07 + .13X_1 + .71X_2$ (.57) (1.73)	.51	.19
November	$.03 + .08X_1 + 1.02X_2$ (1.38) (25.71)	.85	.17	$.00 + .35X_1 + 1.11X_2$ (6.16) (18.42)	.79	.14
December	$.02 + .14X_1 + .97X_2$ (2.21) (56.47)	.95	.11	$.03 + .17X_1 + .97X_2$ (1.55) (50.17)	.96	.18
January	$.01 + .06X_1 + .97X_2$ (1.39) (56.76)	.95	.13	$.03 + .06X_1 + .98X_2$ (.79) (53.14)	.95	.17
February	$.00 + .11X_1 + .99X_2$ (1.30) (71.60)	.98	.11	$-.01 + .26X_1 + .99X_2$ (3.98) (101.43)	.99	.09
March	$.01 + .28X_1 + .93X_2$ (5.13) (43.75)	.96	.11	$.02 + .37X_1 + .93X_2$ (7.06) (38.00)	.94	.13
April	$.05 + .07X_1 + .68X_2$ (.67) (4.33)	.35	.16	$.07 + .31X_1 + .91X_2$ (2.70) (12.34)	.82	.16

a/ Dependent variable is moisture index in the indicated region, X_1 is moisture index at Davis on day D, X_2 is moisture index in the indicated region on day D-1, and figures in parentheses are t-ratios.

b/ Standard error of estimate.

Daily observations of rainfall and pan evaporation were available for the Davis weather station from May 1, 1926, to the present. The values of net change (gain or loss) in moisture were computed for each day and grouped by month and frequency tabulations made as in Appendix Table B–6. Converted to proportions, these frequency tabulations give the probabilities of various daily changes in the moisture index for each of the wet season months.[1]

To generate moisture index values, the value on September 30 is set at zero. A change value is then selected randomly from the October probability distribution for October 1 and added to the previous day value, and so on. These values then are inserted in the Appendix Table B–5 equations to generate moisture index values for all other areas. In generating these values an additional random component is added to each prediction by using the standard errors of estimate (SE values) in Table 8 and an assumed normal distribution.

Transit and Storage Losses

Transit and storage losses consist of changes in beet weight and sugar content after the beets have been harvested. Weight loss is due mainly to dehydration, while sugar loss is due principally to respiratory activities. Both are affected by temperature level [1, 6]. Sugar losses are important since they reach high levels at the higher temperatures. Because of this, the time and distances that beets are shipped and the length of time that beets are stored at the factory must be considered.

The effects of temperature on weight and sugar losses were estimated by fitting least–squares regressions to observations of both in–transit and in–storage losses and the associated daily temperatures, with the following results:[2]

$$WL = -.026476 + .000572238 \text{ TEMP}$$

$$\ln SL = -8.57178 + .0055808 \text{ TEMP}$$

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[1] It would have been possible to tabulate frequency distributions for each day based on 44 annual observations. However, this has the double disadvantage of providing very few observations for some ranges of change while increasing the size of the table by a factor of about 30. The monthly groupings seemed the best compromise.

[2] The data, obtained from records of the Spreckels Sugar Division, consisted of 29 observations of transit and factory losses. The time length of observations varied from 2 to 20 days over a temperature range of 90 °F. to 46.8 °F. measured at the railcar or at the factory pile. The t ratios for the TEMP coefficient were 14.35 for WL and 10.51 for SL, an indication of high levels of statistical significance. The coefficients of multiple determination (R^2) were .88 for WL and .81 for SL. The values of the Durbin–Watson statistic were 1.97 for WL and 1.46 for SL being in the acceptable and inconclusive range, respectively, with regard to the hypothesis of no serial correlation of residuals.

APPENDIX TABLE B-6

Probability Distribution of Net Change in Moisture Index Per Day by Month, Davis, 1926-1970

Moisture index class interval	October		November		December		January		February		March		April	
	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion
inches														
- .99 to - .90	a/													
- .89 to - .80	1	.001											1	.001
- .79 to - .70														
- .69 to - .60	2	.001									1	.001	4	.003
- .59 to - .50	10	.007									7	.005	9	.007
- .49 to - .40	19	.014	3	.002					1	.001	5	.004	27	.020
- .39 to - .30	71	.052	13	.010	1	.001	2	.001	8	.006	36	.026	130	.099
- .29 to - .20	300	.220	57	.043	19	.014	16	.012	50	.040	150	.110	511	.387
- .19 to - .10	739	.542	304	.230	75	.055	67	.050	238	.191	641	.470	411	.312
- .09 to .00	145	.106	748	.567	942	.691	890	.662	640	.515	292	.214	92	.069
.01 to .10	23	.017	58	.044	98	.072	115	.086	79	.064	68	.050	39	.030
.11 to .20	9	.007	34	.026	50	.037	57	.042	54	.043	36	.026	35	.023
.21 to .30	12	.009	16	.012	38	.028	56	.042	40	.032	40	.029	20	.015
.31 to .40	8	.006	21	.016	25	.018	24	.018	27	.022	18	.013	10	.007
.41 to .50	3	.002	19	.014	25	.018	22	.016	20	.016	18	.013	8	.006
.51 to .60	5	.004	16	.012	15	.011	22	.016	19	.015	13	.010	6	.004
.61 to .70	2	.001	8	.006	11	.008	11	.008	13	.010	12	.009	2	.002
.71 to .80	6	.004	4	.003	6	.004	11	.008	18	.014	8	.006	7	.005
.81 to .90			7	.005	13	.010	9	.006	8	.006	6	.004	1	.001
.91 to 1.00	2	.001			14	.010	10	.008	6	.005	2	.001	3	.002
1.01 to 1.10	1	.001			7	.005	6	.004	4	.003	5	.004	3	.002
1.11 to 1.20	1	.001	3	.002	7	.005	7	.005	3	.002	1	.001		
1.21 to 1.30			4	.003	3	.002	2	.002	2	.002	2	.001	1	.001
1.31 to 1.40	2	.001			4	.003	1	.001	2	.002	1	.001		
1.41 to 1.50			1	.001	2	.001	4	.003	2	.002			1	.001
1.51 to 1.60			2	.002	1	.001	2	.001	2	.002			1	.001
1.61 to 1.70			1	.001	1	.001			1	.001			1	.001
1.71 to 1.80					1	.001	3	.002						

(Continued on next page.)

APPENDIX TABLE B-6--continued.

Moisture index class interval inches	October		November		December		January		February		March		April	
	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion	Fre-quency	Pro-portion
1.81 to 1.90			1	.001			1	.001	1	.001	1	.001		
1.91 to 2.00	1	.001					1	.001	1	.001	1	.001		
2.01 to 2.10					2	.001	1	.001						
2.11 to 2.20							2	.001					1	.001
2.21 to 2.30							1	.001	1	.001				
2.31 to 2.40	1	.001							1	.001				
2.41 to 2.50					1	.001								
2.51 to 2.60														
2.61 to 2.70														
2.71 to 2.80					1	.001	2	.001						
2.81 to 2.90									1	.001				
2.91 to 3.00									1	.001				
3.01 to 3.10					1	.001								
3.11 to 3.20														
3.21 to 3.30							1	.001						
3.31 to 3.40														
3.41 to 3.50	1	.001												
3.51 to 3.60														
Total	1,364	1.000	1,320	1.000	1,363	1.000	1,346	1.000	1,243	1.000	1,364	1.000	1,319	1.000
Mean	-.1421		-.0238		.0628		.0766		.0321		-.0616		-.1588	
Standard deviation	.2100		.2136		.2941		.3189		.3035		.2314		.2193	

a/ Blanks indicate zero.

Source: Computed from data from U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Climatological Data--California Section.

where

WL = weight loss per day expressed as a proportion of original weight

SL = sugar loss per day expressed as a proportion of original weight of sugar in the beets

and

TEMP = average daily temperature (°F.).

The weight loss was taken as a linear function of temperature, whereas the sugar losses were expressed in natural logarithms.[1] These equations were used to derive weight and sugar losses for beets in transit and in storage at the factory (see Blocks 37, 42, and 43 of Appendix A). Monthly averages of daily temperatures in areas of harvest (Appendix Table B–7) rather than randomly determined temperatures were substituted in these equations to obtain transit loss rates (loss per ton per day) for each area and period. A random term was not added since fluctuations were relatively small. This value was then multiplied by the estimated standard time (fractions of days) in transit for each receiving station–factory combination to obtain the loss per ton for beets traveling that route. Losses per ton per day in factory storage were also calculated using the average monthly temperature for the weather station nearest the plant.

Tons Sliced Per Day

Because of breakdowns and variations in operating conditions, it is impossible for a factory to always process exactly the same quantity of beets each day. To allow for this, the model permits the daily slice (or average daily slice for semimonth periods) to vary randomly according to a historically determined distribution.

Examination of daily records of quantity of beets sliced for the years 1965–1970 suggested the need for separate distributions for each of four seasonal time periods. These are: first day of operation, start–up period (days 2–5), normal operation (semimonth periods), and operation during raining periods (wet season). For the first day's operation, the mean value was used with no variation; for the other three periods, a normal distribution was specified with means and standard deviations as given in Appendix Table B–8. Chi–square values for the goodness of fit of the normal distribution are also given in the table. The test suggests that it is a good approximation.

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[1] For temperatures below 46.27 °F., the equation predicts a weight gain. Earlier we indicated that weight gains are attributable to water absorption. The weight gain associated with low temperature reflects the fact that low temperatures typically occur during rainy months. The degree of bias involved does not appear to be serious.

APPENDIX TABLE B-7

Monthly Average Mean Temperatures, °F., 1951-1970

Month	Station: Woodland (D-3)	Stockton (D-2)	Corcoran (D-4)[a/]	Salinas (D-1)[b/]
	°F.			
January	45.2	45.1	44.9	49.9
February	50.5	49.8	49.8	52.1
March	53.7	53.1	54.1	52.6
April	59.3	58.5	60.6	55.0
May	65.8	65.4	68.0	57.8
June	72.3	71.8	75.3	60.3
July	76.5	77.2	81.8	61.6
August	75.1	75.9	80.0	62.2
September	72.0	72.2	74.2	63.7
October	64.2	63.9	64.5	61.3
November	53.8	53.1	53.0	55.8
December	46.2	45.5	44.9	51.1

a/ Corcoran Irrigation District.

b/ The years 1958 and 1959 are not included since they are not published.

APPENDIX TABLE B-8

Type of Operation and Tonnage of Beets Sliced Per Day by Factory
Mean Value and Standard Deviation

Type of operation and factory	Mean	Standard deviation	Test to fit to normal random distribution	
			X^2	$X^2_{.05}$ d.f.
			Statistic	
	tons per day			
First day				
F-1	2,353	a/		
F-2	2,260			
F-3	2,245			
F-4	2,514			
Start-up				
F-1	4,877	830	2.41	14.07
F-2	3,920	481	.50	3.81
F-3	3,298	319	6.80	14.07
F-4	3,457	499	1.71	7.82
Normal				
F-1	6,004	459	11.89	14.07
F-2	4,021	454	5.61	11.07
F-3	3,441	206	9.20	14.07
F-4	3,888	405	10.82	14.07
Rain				
F-1	5,943	747	7.92	11.07
F-2	4,163	448	7.24	11.07
F-3	3,408	207	1.78	11.07
F-4	4,184	439	8.67	11.07

a/ Blanks indicate there was no variation.

Rail Delays

During certain periods when the deliveries of beets to the factories consist entirely or principally of deliveries via rail, late trains which are beyond the control of the processor can cause reductions in the amount sliced if inventory levels are reduced to zero. Data on reductions in slice due to late train arrivals were examined for the years 1965–1970 and used to establish the frequency distributions given in Appendix Table B–9. The values pertain to the tons of slice reduced in a semimonth period. In the periods not listed in the table, reductions in slice due to rail delays are not important since the pattern and timing of local deliveries eliminate the problem. To generate the values for rail delays used in the simulation model, a random number was generated which established the amount of the delay (based upon the proportions listed in Appendix Table B–9). When an interval is indicated, the midpoint of the class was used as the delay loss.

APPENDIX TABLE B-9

Slice Reductions Due to Train Delays by Factory and Time Period

Amount of delay loss in semi-month period	Factory and relevant semimonth period							
	F-1		F-2		F-3		F-4	
	July I-September II						April I-June II	
	Number of obser-vations	Pro-portion	Number of obser-vations	Pro-portion	Number of obser-vations	Pro-portion	Number of obser-vations	Pro-portion
tons								
0	20	.741	9	.500	15	.500	14	.484
01-500	2	.074	3	.166	7	.234	5	.172
501-1,000	2	.074	2	.111	3	.100	1	.034
1,001-1,500	1	.037	2	.111	1	.033	3	.103
1,501-2,000	0	--[a]	1	.056	1	.033	0	--
2,001-2,500	1	.037	1	.056	1	.033	2	.069
> 2,500	1	.037	0	--	2	.067	4	.138
TOTAL	27	1.000	18	1.000	30	1.000	29	1.000

a/ Dashes indicate zero.

APPENDIX C

Extraction Rates and Cost Parameters

APPENDIX TABLE C-1

Yield and Clean Beet Percentages by Campaign and Production Area

Production area	Yield by campaign		Clean beet percentage by campaign	
	Fall	Spring	Fall	Spring
	tons per acre		percent	
1	21.42	--[a]	93.81	--
2	26.11	--	93.12	--
3	22.98	--	92.78	--
4	25.95	--	94.30	--
5	21.67	24.11	91.94	91.70
6	21.33	--	92.27	--
7	18.44	--	91.90	--
8	22.62	24.18	91.97	90.08
9	19.59	--	92.66	--
10	21.79	--	93.67	--
11	20.79	--	92.45	--
12	19.16	21.58	91.89	91.07
13	16.22	19.98	91.37	89.52
14	19.71	21.19	92.44	90.43
15	17.89	--	91.49	--
16	21.04	17.69	91.43	88.84
17	19.80	22.97	92.40	91.22
18	18.51	21.21	92.19	91.05
19	17.28	22.34	90.61	89.80
20	18.74	21.75	91.51	90.26
21	24.46	--	93.31	--
22	21.75	--	92.48	--
23	24.50	--	93.45	--
24	22.38	--	93.54	--
25	21.49	20.83	93.00	91.55
26	19.15	--	92.68	--
27	18.00	--	92.40	--
28	28.41	--	93.27	--
29	23.39	--	93.51	--
30	21.90	26.67	92.51	92.10
31	19.88	20.04	92.52	91.43
32	20.50	--	93.22	--
33	19.39	--	92.97	--
34	17.84	--	91.91	--
35	23.38	--	94.59	--

a/ Dashes indicate no harvesting.

Source: Records of Spreckels Sugar Division.

APPENDIX TABLE C-2

Extraction Rates by Factory and Time Period

Time period	F-1	F-2	F-3	F-4
Fall (I = 1, 14)	90.39	72.76	91.21	91.84
Spring (I = 15, 21)	96.93	81.44	95.53	94.92
May II-June II (I = 22, 24)	96.93	81.44	95.53	92.10

Source: Records of Spreckels Sugar Division.

APPENDIX TABLE C-3

Number of Days in Each Period

I	Period	Number of days
1	July I	15
2	II	16
3	August I	15
4	II	16
5	September I	15
6	II	15
7	October I	15
8	II	16
9	November I	15
10	II	15
11	December I	15
12	II	16
13	January I	15
14	II	16
15	February I	15
16	II	13
17	March I	15
18	II	16
19	April I	15
20	II	15
21	May I	15
22	II	16
23	June I	15
24	II	15

APPENDIX TABLE C-4

Cost of Producing Fall and Spring Harvested Beets, 1971 Input Prices

Type of operation and cost	Time	Cost per acre: Labor	Tractor, fuel, and repair	Material	Total	
	hours per acre					
Seed bed preparation						
Plow (1X)	.67	$ 1.34	$3.87	$ --[a]	$ 5.21	
Land plane (2X)	.50	1.00	2.90	--	3.90	
Float (1X)	.25	.50	1.45	--	1.95	
Chisel (2X)	.80	1.60	4.64	--	6.24	
Disc (2X)	.50	1.00	2.90	--	3.90	
Springtooth (1X)	.17	.34	.99	--	1.33	
List and fertilize (84 units N @ 9¢)	.20	.40	.60	7.56	8.56	
Move equipment, set up, and service (10 percent of operating time)	.31	.62	--	--	.62	
Subtotal	3.40	$ 6.80	$17.35	$ 7.56	$ 31.71	
Planting						
Sled plant and incorporate (1 man)	.40	$ .80	$2.05	$ --	$ 2.85	
Starter fertilizer (8-24-0, 16 units N 200 lbs. @ $77 per ton)	--	--	--	7.70	7.70	
Herbicide (10" ban, 5 lbs.)	--	--	--	6.00	6.00	
Seed (3 lbs. @ $1.50 per pound)	--	--	--	4.50	4.50	
Move equipment, set up, and service (15 percent of operating time)	.06	.12	--	--	.12	
Subtotal	.46	$ .92	$ 2.05	$18.20	$ 21.17	
Growing (in sequence)						
Roll (1X)	.20	$ .35	$ .30	$ --	$ .65	
Ditch (1X)	.03	.06	.17	--	.23	
Irrigate (2X)	--	2.44	--	4.75	7.19	
Plow ditch (1X)	.01	.02	.06	--	.08	
Insect control--cutworm bait (fly on)	--	--	--	5.50	5.50	
Thin--mechanical custom	--	--	--	12.00	12.00	
First cultivation	.30	.60	1.25	--	1.85	
Fertilize--side dress (50 units N @ 9¢)	.25	.50	.90	4.50	5.90	
Post thinning herbicide	--	--	--	4.00	4.00	
Second cultivation--furrow out	.30	.60	1.25	--	1.85	
Ditch	.03	.06	.17	--	.23	
Irrigate (2X)	--	2.44	--	4.75	7.19	
Plow ditch	.01	.02	.06	--	.08	
Third cultivation	.30	.60	1.25	--	1.85	
Hoe	--	15.00	--	--	15.00	
Fourth cultivation--furrow out	.30	.60	1.25	--	1.85	
Ditch	.03	.06	.17	--	.23	
Irrigate (4X)	--	4.88	--	9.50	14.38	
Plow ditch	.01	.02	.06	--	.08	
Miscellaneous irrigation equipment	--	--	--	.25	.25	
Move equipment, set up, and service (15 percent of operating time)	.27	4.12	--	--	4.12	
Subtotal	2.04	$32.37	$ 6.89	$45.25	$ 84.51	
TOTAL		$40.09	$26.29	$71.01	$137.39	
Other production						
Miscellaneous growing cost (11 percent of growing costs)	$9.30					
Workmen's Compensation Insurance, Social Security, and fringe benefits (12 percent of cash wage)	4.71					
Interest ($110 per acre--4½ months at 10 percent)[b]	4.12					
Subtotal					$ 18.13	
TOTAL CULTURAL COST (FALL HARVEST)						$155.52
Additional (Spring)						
Fall irrigation (1X)	$3.60					
Interest	4.58					
Subtotal					$ 8.18	
TOTAL CULTURAL COST (SPRING HARVEST)						$163.70

Assumptions

Track layer	$5.00 per hour	10-hour day, 100-acre field
Fuel and maintenance	$ .80 per hour	1/2 acre-foot per irrigation
Large wheeled tractor	$2.50 per hour	$4.75 per acre-foot for water
Fuel and maintenance	$ .50 per hour	Cost of irrigator and pickup
Small wheeled tractor	$1.00 per hour	$1.22 per acre per irrigation
Fuel and maintenance	$ .50 per hour	
Tractor driver		
Skilled	$2.00 per hour	
Unskilled	$1.75 per hour	

a/ Dashes indicate not applicable.

b/ This quantity assumes $11,000 is borrowed for 100 acres: $4,000 (labor); $1,700 (water); $2,700 (thinning and hoeing); $200 (application); and $2,400 (fertilizer). One-half of the amount is borrowed for 6 months while the other half is borrowed for 3 months, an average of 4½ months for the total.

Source: Discussions with personnel of Spreckels Sugar Division; also, Agricultural Extension Service sample costs of production.

APPENDIX TABLE C-5

Summary of Sugar Beet Cultural Costs Per Acre by Production Area

Production area	Land preparation a/	Planting a/	Ditch and plow ditch	Irrigation b/	All fertilization	Insect control c/	Cultivation	Herbicide c/	Weeding and thinning	Miscellaneous growing costs	Total	Other production costs	Total cultural cost, fall harvest	Additional spring costs	Total cultural cost, spring harvest
	dollars per acre														
1-4	24.15	8.12	--d/	18.10	25.64	e/	7.40	20.00	25.00	4.37	132.18	18.13	150.91	f/	
5-6	24.15	8.12	.93	24.80	17.56	5.50	7.40	10.00	27.00	4.37	129.83	18.13	147.96	7.68	155.64
7	24.15	8.12	--	9.72	17.56	5.50	11.10	10.00	27.00	4.37	117.52	18.13	135.65		
8-10	24.15	8.12	.93	24.80	17.56	5.50	7.40	10.00	27.00	4.37	129.83	18.13	147.96	7.68	155.64
11	24.15	8.12	--	9.72	17.56	5.50	11.10	10.00	27.00	4.37	117.52	18.13	135.65		
12-20	24.15	8.12	.93	28.76	21.16	5.50	7.40	10.00	27.00	4.37	137.39	18.13	155.52	8.18	163.70
21	24.15	8.12	.31	54.67	17.56	7.70	7.40	13.00	25.00	4.37	162.28	18.13	180.41		
22	24.15	8.12	1.55	72.00	17.14	9.50	11.10	20.00	35.00	4.37	206.93	18.13	221.06		
23	24.15	8.12	1.24	58.50	18.10	7.70	9.25	15.00	27.00	4.37	173.43	18.13	191.56		
24	24.15	8.12	.93	40.20	12.20	7.70	7.40	16.00	26.00	4.37	147.07	18.13	165.20		
25	24.15	8.12	.62	20.96	19.81	12.00	5.55	11.00	28.00	4.37	134.58	18.13	152.71	9.82	162.53
26	24.15	8.12	.93	32.64	17.20	23.50	7.40	13.40	23.50	4.37	155.21	18.13	173.34		
27	24.15	8.12	1.24	72.00	16.64	9.50	10.18	20.00	35.00	4.37	214.95	18.13	219.33		
28	24.15	8.12	--	77.12	20.71	7.00	5.55	16.00	23.50	4.37	186.52	18.13	204.65		
29	24.15	8.12	1.24	49.14	16.66	7.70	9.25	14.00	23.00	4.37	157.63	18.13	175.76		
30	24.15	8.12	.62	15.32	21.16	12.00	5.55	11.00	28.00	4.37	130.29	18.13	148.42	8.42	156.84
31	24.15	8.12	--	57.84	20.71	7.00	5.55	16.00	23.50	4.37	167.24	18.13	185.37		
32	24.15	8.12	1.24	54.86	12.20	7.70	9.25	15.00	27.00	4.37	163.89	18.13	182.02		
33	24.15	8.12	.93	32.64	17.20	23.50	7.40	13.40	23.50	4.37	155.21	18.13	173.34		
34	24.15	8.12	1.24	48.00	17.74	9.50	9.25	20.00	30.00	4.37	172.37	18.13	190.50		
35	29.40	8.12	4.00	25.68	30.13	9.00	5.55	15.00	28.00	4.37	159.25	18.13	177.38		

a/ Excluding fertilizer.

b/ For typical number of irrigations.

c/ Including application cost.

d/ Dashes indicate explanation not required (sprinkler irrigation).

e/ None specified.

f/ Blanks indicate no spring harvesting.

Source: Discussions with personnel of Spreckels Sugar Division; also, Agricultural Extension Service sample costs of production.

APPENDIX TABLE C-6

Sugar Beet Cultural Cost Per Acre by Time Period and Production Area

Production area	Time period																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	dollars per acre																							
1-4	150.91	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
5-6	147.96	→	→	→	→	→	→	→	→	→	→	→	→	→	155.64	→	→	→	→	→	→	→	→	→
7	135.65	→	→	→	→	→	→	→	→	→	→	→	→	→										
8-10	147.96	→	→	→	→	→	→	→	→	→	→	→	→	→	155.64	→	→	→	→	→	→	→	→	→
11	135.65	→	→	→	→	→	→	→	→	→	→	→	→	→										
12-20	155.52	→	→	→	→	→	→	→	→	→	→	→	→	→	163.70	→	→	→	→	→	→	→	→	→
21	170.47	175.44	180.41	→	→	→	→	→	→	→	→	→	→	→										165.50
22	←	←	←	←	←	213.06	217.06	221.06	225.06	→	→	→	→	→										
23	179.86	185.71	191.56	→	→	→	→	→	→	→	→	→	→	→										174.01
24	158.50	161.85	165.20	→	→	→	→	→	→	→	→	→	→	→										155.15
25	152.71	→	→	→	→	→	→	→	→	→	→	→	→	→	162.53	→	→	→	→	→	→	→	→	→
26	162.46	165.18	167.90	170.62	173.34	176.06	→	→	→	→	→	→	→	→										
27	183.33	192.33	201.33	210.33	219.33	223.83	237.33	242.33																
28					195.01	199.83	204.65	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
29	164.42	171.98	175.76	→	→	→	→	→	→	→	→	→	→	→										160.64
30	148.42	→	→	→	→	→	→	→	→	→	→	→	→	→	156.84	→	→	→	→	→	→	→	→	→
31	156.45	161.27	166.09	175.73	180.55	185.37	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→
32	169.36	177.80	182.02	→	→	→	→	→	→	→	→	→	→	→										165.14
33	162.46	165.18	167.90	170.62	173.34	176.06	→	→	→	→	→	→	→	→										
34	169.50	172.50	178.50	184.50	187.50	190.50	193.50																	
35	177.38	→																		177.38	→	→	→	→	→

Source: Discussions with personnel of Spreckels Sugar Division; also, Agricultural Extension Service sample costs of production.

APPENDIX TABLE C-7

Computation of Representative Opportunity Cost for Spring Delayed Harvest of Sugar Beets

	Canning tomatoes	Field corn
Price	$27.00 per ton	$2.60 per cwt.
Yield per acre	22 tons	90 cwt.
Gross return per acre	$594	$234
Cost per unit	$24.00 per ton	$2.32 per cwt.
Total cost per acre	$528	$208.80
Net return per acre	$66.00	$25.20
Tomatoes return less corn	$40.80	

Source: University of California, Agricultural Extension Service, Sample Costs of Production, Yolo County, 1969.

APPENDIX TABLE C-8

Receiving Station, Rail, and Transport Costs by Receiving Station

Receiving station	Receiving station cost	Rail cost				Transport cost			
		F-1	F-2	F-3	F-4	F-1	F-2	F-3	F-4
		dollars per ton							
1	.23	2.14	2.82	2.72	2.92	a/			
2	.14	1.71	2.92	3.13	3.33	1.60			
3	.27	2.72	3.54	3.75	4.15	1.65			
4	.18		2.72	2.92	3.13				
5									
6	.17	2.72	2.14	2.72	2.14	2.40	1.60		2.00
7	.27	3.13	2.67	2.14	2.92		2.15	2.00	
8	.13	2.72		2.67	2.67				2.75
9									
10									
11									
12									
13	.18	2 72	2.67	1.90	2.72		2.00	1.40	
14	.16	3.13	2.82	2.14	3.13			1.70	
15									
16		4.22	2.58	3.00	3.72		2.45	1.60	
17	.21	2.72	2.67	1.71	2.72		2.25	1.10	
18	.18	2.92	2.25	1.71	2.72		2.10	1.10	
19									
20	.17	2.92	2.67		2.92				
21	.16	3.95	3.13	3.75	2.72				
22	.17	3.41	2.87	2.98	1.94		2.80		1.30
23	.14	4.14	3.44	4.14	2.72				
24	.18	4.35	3.51	4.12	2.92				
25	.25	2.92	2.61	2.72	1.71	2.60	2.20		1.15
26	.22	3.54	2.74	3.27	2.25				1.80
27	.15	3.33	2.82	2.92	1.71		2.80		1.10
28									
29	.16	3.75	2.92	3.54	2.72				
30	.21	2.92	2.25	2.72	1.90	2.60	1.75		1.50
31	.09	3.13	2.82	2.92					
32	.13	3.75	2.92	3.54	2.72				
33	.18	3.69	2.74	3.27	2.25				
34	.27	3.54	2.82	3.33	2.67				2.00
35	.14		5.30		4.37				

a/ Blanks indicate receiving station in another area; see Appendix Table D-10.

Source: Records of Spreckels Sugar Division.

APPENDIX D

Decision Rules and Decision Parameters–Existing System

APPENDIX D

Decision Rules and Decision Parameters–Existing System

This appendix describes the derivation of the rules by which values are assigned to the decision variables of the system, as initially modeled, and gives the empirical content of these rules.

Preplanting Decision Rules

The five types of preplanting decisions appear in Block 7 of Appendix A.

Total Tonnage and Acreage.––At the time of this study, the management goal was to produce the amount of sugar that could be obtained by maximum use of available factory capacity. Planned total tonnage per year thus is determined by summing expected daily slice rates over the maximum number of days the plant may be expected to operate. These values are summarized by time periods and factories in Appendix Table D–1. They reflect historical experience as to weather restrictions and anticipations of technical factory changes. The initial model sets the total beet quantity goal at 3,862,950 tons. Dividing this value by an expected average yield of 22.1 tons per acre gives a total acreage goal of 174,794 acres. For modeling purposes, these control variables become constants in the computational process rather than functions of state variables. If government regulations were in effect or if management goals were to change, the values of the constants would change. The model then could generate measures of the effects of such changes.

Allocation Among Production Areas.––In the initial model, we have allocated total acreage among production areas according to proportions determined by historical processor practices. The values as applied to the total acreage goal are given in Appendix Table D–2.

Factory Supply Sources.––During some periods of the year, each district (a group of production areas) is unable to supply all of the beets needed by the factory in that district while other districts may have excess supplies. The management practice has been to specify a primary and alternate district supply source for each factory for each time period and a set of priorities when more than one factory is supplied by a given district. The decision rules by which interdistrict shipment patterns are determined are specified in Appendix Table D–3. These rules reflect historical practices based on transportation cost, available supplies, and factory need considerations and are somewhat interrelated with the original allocations of acreages among production areas.

APPENDIX TABLE D-1

Expected Slice Rates by Factory and Production Period
Initial Model

Time period		F-1	F-2	F-3	F-4
		tons per period			
July	I	82,500	61,500	47,250	57,750
	II	88,800	65,600	50,400	61,600
August	I	83,250	61,500	47,250	57,750
	II	88,800	65,600	48,800	61,600
September	I	84,750	61,500	45,750	58,500
	II	84,750	61,500	45,750	58,500
October	I	84,750	61,500	45,750	58,500
	II	90,400	65,600	48,800	62,400
November	I	84,750	61,500	45,750	58,500
	II	56,500	61,500	45,750	58,500
December		--a/	184,500	--	117,000
Spring		249,750	228,000	186,000	213,000
May II-June II		--	--	--	163,300
Total		1,079,000	1,039,800	657,250	1,086,900
TOTAL		3,862,950			

a/ Dashes indicate no operation during that period.

Appendix Table D–3 shows that during July, D–4 supplies all factories. As production starts in other areas, each factory is supplied first by quantities harvested in the local district and then obtains any additional quantities needed from the alternate sources indicated in the table. From July through October, D–4 always has enough beets to supply the factories for which it is the alternate source. In other periods the priorities are local districts first; then other districts as available. When D–2 supplies other factories, the priorities are F–2, F–4, and F–1. When D–3 supplies other factories, the priorities are F–3, F–1, and F–4.

APPENDIX TABLE D-2

Allocation of Total Acreage to Production Areas
Initial Model

Production area	Proportion	Acreage[a/]
1	.01270	2,220
2	.01789	3,127
3	.00433	757
4	.04358	7,618
5	.02309	4,036
6	.02309	4,036
7	.00577	1,009
8	.09336	16,319
9	.00693	1,211
10	.00216	378
11	.00144	252
12	.00768	1,342
13	.01833	3,204
14	.02332	4,076
15	.03544	6,195
16	.00814	1,423
17	.02840	4,964
18	.01440	2,517
19	.00594	1,038
20	.11809	20,641
21	.02144	3,748
22	.01443	2,522
23	.01974	3,450
24	.01297	2,267
25	.03463	6,053
26	.01212	2,119
27	.04617	8,070
28	.02886	5,045
29	.03460	6,048
30	.02540	4,440
31	.14600	25,520
32	.01633	2,854
33	.02540	4,440
34	.02746	4,800
35	.04040	7,062

a/ The sum of this column is 174,801 rather than 174,794 due to a rounding error.

APPENDIX TABLE D-3

Factory Source of Beets by District and Time Period

Time period		F-1		F-2a/		F-3b/		F-4	
		Primary	Alternate	Primary	Alternate	Primary	Alternate	Primary	Alternate
July	I	D-4	c/	D-4		D-4		D-4	
	II	D-4		D-4		D-4		D-4	
August	I	D-1	D-4	D-4		D-3	D-4	D-4	
	II	D-1	D-4	D-2	D-4	D-3	D-4	D-4	
September	I	D-1	D-4	D-2	D-4	D-3	D-4	D-4	
	II	D-1	D-4	D-2	D-4	D-3	D-4	D-4	
October	I	D-1	D-4	D-2	D-4	D-3		D-4	
	II	D-1	D-4	D-2	D-4	D-3		D-4	
November	I	D-3		D-2	D-4	D-3		D-4	
	II	D-3		D-2	D-4	D-3		D-4	
December	I	D-3		D-2	D-4	D-3		D-4	
	II	D-3		D-2	D-4	D-3		D-4	
January	I	D-3		D-2	D-4	D-3		D-4	
	II	D-3		D-2	D-4	D-3		D-4	
February	I	D-3		D-2	D-4	D-3		D-4	
	II	D-3		D-2	D-4	D-3		D-4	
March	I	D-3		D-2	D-4	D-3		D-4	
	II	D-3	D-2	D-2	D-4	D-3		D-4	
April	I	D-3	D-2	D-2	D-4	D-3		D-4	
	II	D-3	D-2	D-2	D-4	D-3		D-4	D-2/D-3
May	I	D-3	D-2	D-2		D-3		D-4	D-2/D-3
	II	D-3	D-2	D-2		D-3		Imperial	
June	I	D-3	D-2	D-2		D-3		Imperial	
	II	D-3	D-2	D-2		D-3		Imperial	

a/ When D-2 supplies factories other than F-2, the priorities are F-2, F-4, and F-1.
b/ When D-3 supplies factories other than F-3, the priorities are F-3, F-1, and F-4.
c/ Blanks indicate no alternate source.

Factory Starting Dates.——F–2, F–3, and F–4 are all specified to begin operations on July 1 and are operated at maximum capabilities. Because of higher costs, the quantity to be processed at F–1 (in the Salinas Valley) during July through October is determined residually. If the total tonnage is less than the full capacity amount (3,862,950 tons in this case), the reduction is taken from the F–1 fall operation. The expected number of days of F–1 operation during this period is determined by dividing the residual quantity by the average daily slice. The starting date for F–1 is then determined by subtracting the expected number of days from 124 (November 1 is day 124) to establish the starting date with July 1 being the earliest possible date.

As the year progresses from the planting period to near the harvest period, probable yields become known with greater certainty; it, therefore, becomes possible to predict more closely the actual tonnage to be harvested. This permits revision in the original starting date calculations for F–1. To account for this in the actual modeling process, a random factor was added to the original expected yield to obtain a revised estimate of total tonnage which was used to determine the final starting date for F–1.[1] In 8 out of 10 years simulated, the final starting date remained at July 1.

Standard Inventory Levels.——Each factory maintains inventories of unprocessed beets as a buffer for continuous operation as well as to extend operations. Management must decide on the target levels of inventories which seem likely to minimize operating costs. The level of inventory desired may vary throughout the season depending on the distance of shipments and weather conditions which may affect the variability and predictability of arrivals. Unnecessarily high inventory levels may increase storage costs and sugar losses, while levels too low may involve costly shutdowns. For the initial model we have assigned values based on the historical practices of the management. These are given in Appendix Table D–4. Actual inventories may, of course, deviate considerably from these values.

Planting Period Decision Rules

There is only one type of decision to be made during the planting period——the time of planting in each producing area. The normal planting periods for the initial historical model are given in Appendix Table D–5. Planting is then assumed to begin as early as weather permits in the planting period and to continue unless interrupted by rain. The pattern of actual planting within each area thus varies from year to year.

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[1] For a discussion on yield equations, see *supra,* page 52.

TABLE D-4

Standard Inventory Levels by Factory and Time Period
Initial Model

Time period		F-1	F-2	F-3	F-4
		tons			
July	I	6,000	1,500	3,000	500
	II	6,000	1,500	3,000	500
August	I	5,500	1,500	1,500	500
	II	5,500	1,500	1,500	500
September	I	2,500	500	500	500
	II	2,500	500	500	500
October	I	2,500	500	500	500
	II	2,500	500	500	500
November	I	4,000	50,500	40,500	25,500
	II	4,000	50,500	40,500	25,500
December	I	4,000	50,500	40,500	25,500
	II	4,000	50,500	40,500	25,500
January	I	4,000	50,500	40,500	25,500
	II	4,000	50,500	40,500	25,500
February	I	4,000	50,500	40,500	25,500
	II	4,000	50,500	40,500	25,500
March	I	4,000	5,000	5,000	5,000
	II	4,000	5,000	5,000	5,000
April	I	4,000	5,000	5,000	5,000
	II	4,000	500	500	500
May	I	4,000	500	500	500
	II	4,000	500	500	500
June	I	4,000	500	500	500
	II	4,000	500	500	500

APPENDIX TABLE D-5

Decision Values that Determine Mean Planting Dates by Production Area

Production area	Normal planting period	Critical values of moisture index	Number of days since moisture index reached zero	Earliest mean planting date
1	December-March	.36	--[a]	10 January
2	December-March	.30	--	10 January
3	December-March	.48	--	20 December
4	December-March	.05	--	1 January
5	March-May	--	28	15 March
6	December-April	.72	--	15 February
7	November-April	--	2	6 March
8	March-May	--	36	18 March
9	November	--	--	26 November
10	March-May	--	3	27 March
11	February-April	--	15	6 February
12	March-May	--	31	23 March
13	March-May	--	28	20 March
14	March-May	--	28	27 March
15	January-March	.48	--	15 January
16	February-April	--	8	26 February
17	March-May	--	28	21 March
18	March-May	--	33	23 March
19	March-May	--	27	27 March
20	February-May	--	30	19 March
21	December-February	.79	--	1 January
22	December-March	--	12	1 February
23	December-February	.48	--	8 January
24	December-February	.58	--	1 January
25	March-May	--	49	5 March
26	October-February	.38	--	1 January
27	October-January	.42	--	12 November
28	December-March	--	14	26 November
29	December-February	.55	--	8 January
30	March-May	--	39	5 March
31	October-March	.27	--	8 January
32	December-February	.54	--	15 January
33	November-February	.38	--	1 January
34	October-February	.66	--	12 November
35	September-October	--	--	24 September

a/ Dashes indicate not applicable.

Note: See text for explanation.

Since the available planting and harvest data pertain only to production area totals, we were not able to model the planting decisions by individual fields or farms. Therefore, we formulated the model to establish a mean planting date (when 50 percent of the acreage has been planted) for each area as a function of moisture index values.

Examination of records of weekly acres planted in each production area indicated that in some areas the mean planting date tended to occur at positive values of the moisture index and in others only after the moisture index had dropped to zero. This may reflect differences in soil characteristics, delays to permit aphid flights to decline before planting, variations in moisture within production areas, and differences in planting distribution patterns around the mean date.

For the first case (planting with positive moisture index values), critical values were determined as averages for recent years of the value of the moisture index when 50 percent of the area acreage has been planted. The moisture index declines as the soil drys, and the date when it reaches the critical level is specified as the mean planting date for that area. These values are given in column 3 of Appendix Table D–5.

For the second case, the date when the moisture index drops to zero is used as a base. The critical value then is the average number of days from zero moisture until 50 percent of the area acreage has been planted. The number of days from zero moisture which determine the mean planting date in particular areas is given in column 4 of Appendix Table D–5. If at any time the sum of moisture values for five consecutive days exceeds 0.50, the counting of number of days is started over when the moisture index again drops to zero. This allows for a rainstorm to delay planting.

To insure that planting occurs only within the designated normal planting periods, a date was specified as the earliest at which 50 percent of an area's acreage could be planted. These values are given in column 5 of Appendix Table D–5. Thus, the date when a critical value of the moisture index has been reached is specified as the mean planting date only if it is the same as or later than the earliest mean planting date. There are no critical values for Areas 9 and 35. Planting occurs here prior to the heavy rains. Thus, the mean planting dates are the earliest possible dates.

Harvest Period Decision Rules

The four types of decisions to be made during the harvest period appear in Blocks 19, 20, 28, and 16 of Appendix A. The first three types of decisions are interrelated.

Quantity of Beets Harvested in Each District.––The decision rules for determining the quantities to be harvested vary by time period and are modified by random weather factors during the wet season.

Figure 2 diagrams the rule used for each semimonth period during *July–September.* Since there is virtually no rain, desired and actual quantities harvested coincide exactly. The procedure is simply to determine first the amount (tonnage) in each district needed to supply the local factory. If the amount available to harvest is less than the amount required, the available quantity is harvested.[1] If the amount available exceeds the local factory requirements, it is necessary to check to see if there are unfilled factory requirements in other districts, following the source rules or Appendix Table D–3. The process continues, as illustrated in Figure 2, until all district harvest quantities have been set.

In *May and June,* the remaining dry period, there is no harvest in D–1; and all D–4 quantities are utilized by F–4 (Appendix Table D–3). The rule for determining the quantities harvested in D–2 and D–3 is formulated so that each district will complete its harvest at approximately the same time. This reflects a processor policy to maintain good relations with growers by avoiding having growers in one district required to harvest well into the spring while the other district completes much earlier.

The decision procedure in each period is first to determine total requirements for F–1, F–2, and F–3 plus any amounts required of F–4 that cannot be supplied by D–4. Since all acreage in D–2 and D–3 can be harvested at this point, the total requirements are allocated to the two districts according to the remaining unharvested tonnage in each district. The decision rule may be expressed in equation form as follows:

$$H_2 = \frac{U_2}{U_2 + U_3} [R_1 + R_2 + R_3 + (R_4 - A_4)]$$

and

$$H_3 = \frac{U_3}{U_2 + U_3} [R_1 + R_2 + R_3 + (R_4 - A_4)]$$

where

H = quantity harvested

U = quantity still unharvested

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[1] For a discussion on behavioral relationships, see *supra,* page 17.

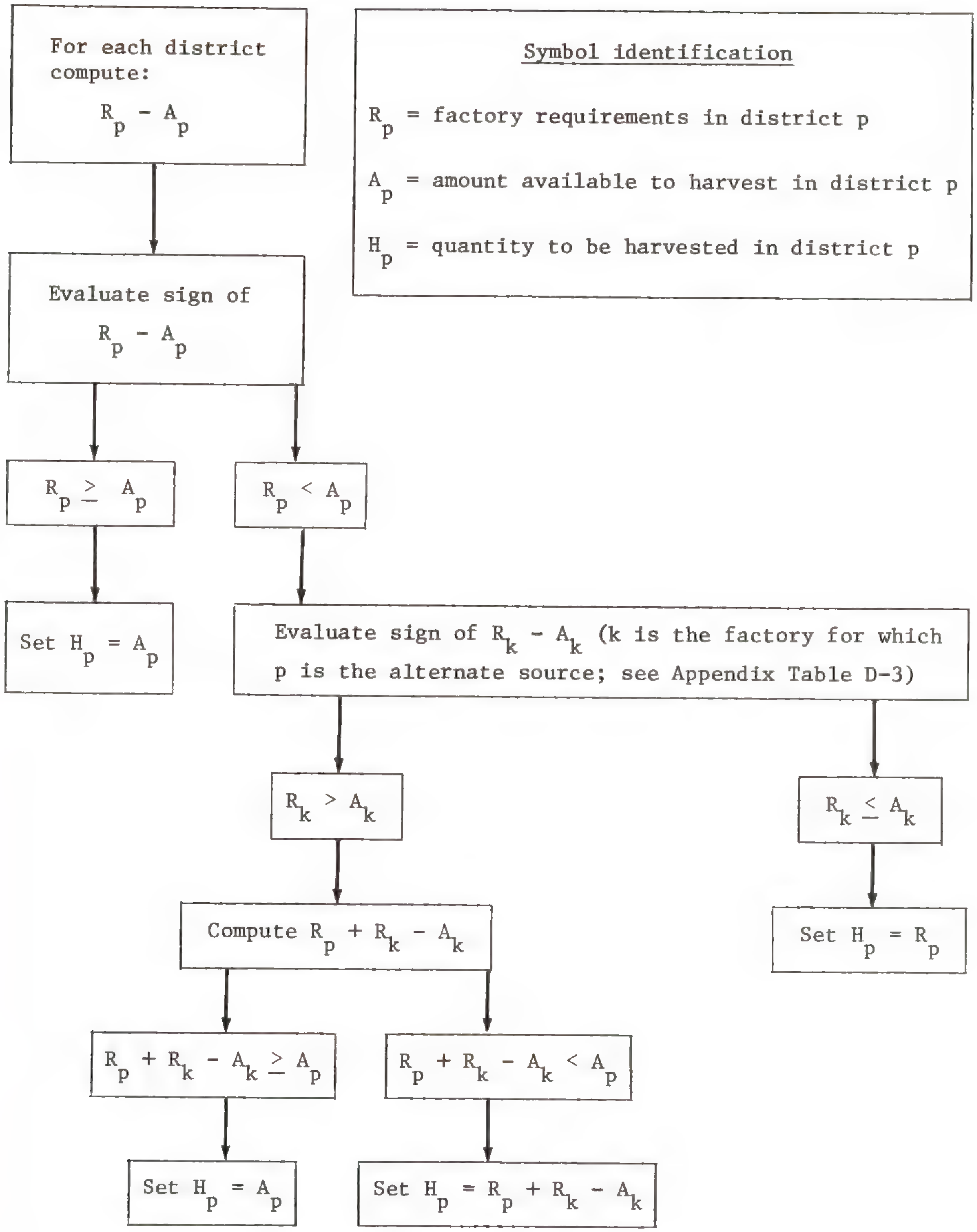

FIGURE 2. Decision Rule for Determining Quantity to be Harvested in Each District for Each Semimonth Period During July-September

R = factory requirement

A = amount available for harvest

and

subscripts refer to districts.

When Imperial is supplying F–4, the term, $R_4 - A_4$, drops out. The harvested quantities are then allocated to factories according to Appendix Table D–3 and the priorities specified previously.

During the wet season, October–April, the desired harvest levels are modified by probability values that vary randomly in relation to the level of the moisture index as shown in Appendix Table D–6. The table indicated, for example, that, if the moisture index is between .75 and .99, the probability of zero harvest is .219; the probability that it will be between 1 and 24 percent of normal is .290, and so on. The harvest decision rule is as follows:

1. Determine normal daily factory requirements by reference to Appendix Table D–7.

2. Determine desired quantity harvested in each district as indicated in Figure 2.

3. Observe moisture index value generated for that date.

4. Enter Appendix Table D–6 to obtain the proportion of normal harvest for that date. Use midpoint values of proportion classes. If moisture index is zero, the proportion of normal harvest is 1.0.

5. Set quantity to be harvested equal to the desired quantity multiplied by the proportion of normal harvest.

Allocations of District Quantities Harvested to Production Areas.––Given the decisions on district quantities, the next step is to allocate these quantities to the several producing areas within each district. These decisions are based on the availability of beets to be harvested in each area, the capacities or receiving stations, previously specified target completion dates, and a set of quotas. The decision rules are different for each district and again are modified by moisture index during the wet season.

APPENDIX TABLE D-6

Wet Season Beet Harvest: Daily Proportion of Normal Harvest in Relation to Moisture Index[a/]

Moisture index interval inches	Proportion of normal harvest						Total
	Composite of all districts						
	0	.01-.24	.25-.49	.50-.74	.75-.99	1.00	
.01-.24							
Number of observations	6	25	31	19	20	34	135
Proportion	.044	.185	.230	.141	.148	.252	1.000
.25-.49							
Number of observations	13	29	16	17	12	23	110
Proportion	.118	.264	.145	.155	.109	.209	1.000
.50-.74							
Number of observations	24	33	17	13	8	16	111
Proportion	.216	.298	.153	.117	.072	.144	1.000
.75-.99							
Number of observations	25	33	20	14	8	14	114
Proportion	.219	.290	.175	.123	.070	.123	1.000
1.00-1.24							
Number of observations	31	21	16	9	5	3	85
Proportion	.365	.247	.188	.106	.059	.035	1.000
1.25-1.49							
Number of observations	32	20	3	3	b/	1	59
Proportion	.542	.339	.051	.051		.017	1.000
1.50-1.74							
Number of observations	21	8					29
Proportion	.724	.276					1.000
1.75-1.00							
Number of observations	34	12	17	4			67
Proportion	.507	.179	.254	.060			1.000
2.00							
Number of observations	21	4					25
Proportion	.840	.160					1.000

a/ To estimate these relationships, records of daily harvested tonnage in each district for 1965-1970 were expressed as proportions of normal harvest to eliminate the effect of the difference in harvest level at different times of the year. For this purpose, normal harvest values were approximated by examining the levels of the day's harvest in relation to harvest before and after this day and by considering the number of factories each district was supplying--the latter being necessary since the normal harvest level for each district varies with the number of factories supplied.

b/ Blanks indicate zero.

APPENDIX TABLE D-7

Normal Factory Requirements by Time Period[a/]

Time period		F-1	F-2	F-3	F-4
		tons per day			
October	I	8,100	4,700	3,900	4,700
	II	8,100	4,700	3,900	4,700
November	I	9,600	8,200	7,400	6,200
	II	9,600	8,200	7,400	6,200
December	I	9,600	8,200	7,400	6,200
	II	9,600	8,200	7,400	6,200
January	I	9,600	8,200	7,400	6,200
	II	9,600	8,200	7,400	6,200
February	I	9,600	8,200	7,400	6,200
	II	9,600	8,200	7,400	6,200
March	I	9,600	4,700	3,900	4,700
	II	9,600	4,700	3,900	4,700
April	I	9,600	4,700	3,900	4,700
	II	9,600	4,700	3,900	4,700

a/ Daily amounts needed to process and to adjust levels of inventories to the standard values given in Table 16.

D–1, which includes production Areas 1–4, has insufficient production to supply the local factory (F–1) during much of the year, so harvest is in accordance with the availability of beets. The allocation rule during *July–September* is as follows:

Let:

(1) H_1 = amount harvested in D–1 as determined previously

R_1 = factory requirement for F–1 in each semimonth period

H_{1j} = amount harvested in area j

and

A_{1j} = amount available in area j.

(2) If $R_1 - H_1 \geqslant 0$, set $H_{1j} = A_{1j}$ for all areas.

(3) If $R_1 - H_1 < 0$, set $H_{1j} = A_{1j}$ for Areas 1–3; set $H_{14} = R_1 - \sum_{j=1}^{3} A_{1j}$.

In October, the only month of wet season operation in this district, the decision rule is to allocate the daily quantity to be harvested in the district to the four production areas using percentages 11, 31, and 58 for Areas 1, 2, and 4, respectively. Area 3 already has completed harvest and, as one of the other areas completes harvest, the percentage for that area is set at zero; and its allocation is given to the other areas in proportion to their contribution to the total.

In *D–2,* which includes production Areas 5–11, the decision rule reflects a desire to complete harvest in certain areas in the fall to meet the requirements of the beet–free area in the district.[1] The rule for *July–September* is as follows:

(1) Compute $R_2 - H_2$ as for D–1.

(2) If $R_2 - H_2 \geqslant 0$, set $H_{2j} = A_{2j}$ for all areas.

---

[1] See *supra,* page 4.

(3) If $R_2 - H_2 < 0$, set $H_{2j} = A_{2j}$ for Areas 5, 6, 7, 9, 10, 11;

set $H_{2,8} = H_2 - (A_{2,5} + A_{2,6} + A_{2,7} + A_{2,9} + A_{2,10} + A_{2,11})$.

The allocation rule for *May–June* is obtained by first determining the unharvested tonnage remaining in each area (U_{2j}). The district harvest quantities are then allocated proportionately to production areas according to

$$H_{2j} = \frac{U_{2j}}{\sum_{j=5}^{11} U_{2j}} H_2.$$

This rule merely states that each area harvests the proportion of the district's total (H_2) that is represented by its contribution of the district's remaining tonnage.

During *October–April,* the district quantities are allocated by two methods, depending on the value of the moisture index. If the moisture index is zero, the allocation rule described for May and June is used. If the moisture index is positive, the allocation is made in accordance with the proportions given in Appendix Table D–8. These proportions were determined from weekly harvest records for the period 1965–1970 and thus reflect the historical decision rules. Production areas not listed would have no harvest during the wet period.

D–3 consists of production Areas 12–20. During July–September, the D–3 quantity available for harvest is less than or equal to the F–3 requirement. Therefore, the amount harvested each period in each producing area is the amount available.

In May and June the allocation rule is similar to that for D–2. That is,

$$H_{3j} = \frac{U_{3j}}{\sum_{j=12}^{20} U_{3j}} H_3.$$

During the wet season, the district quantities are again allocated by two methods. If the value for the moisture index is zero, the following allocation rule is used:

APPENDIX TABLE D-8

Allocation of the Proportion of Quantity Harvested in District Among Various Production Areas Depending on the Moisture Index

District and production area	Proportion of quantity harvested in district among production areas with moisture index of:				
	.01-.24 inches	.25-.49 inches	.50-.99 inches	1.00-1.49 inches	> 1.50 inches
	proportion				
D-2					
5	.123	.123	.152	.176	--a/
8	.877	.877	.842	.824	1.000
Total	1.000	1.000	1.000	1.000	1.000
D-3 (Fall, October-January)					
12	.080	.060	.130	.300	.300
13	.070	.050	.140	.090	.090
14	.090	.070	.080	--	--
17	.090	.110	.050	--	--
18	.060	.060	.070	--	--
19	.030	.040	.160	.110	.110
20	.580	.610	.490	.500	.500
Total	1.000	1.000	1.000	1.000	1.000
D-3 (Spring, February-April)					
12	.020	.030	.010	--	--
13	.040	--	.050	--	--
14	.160	.420	.240	--	--
17	.150	.020	.050	--	--
18	.120	.090	.080	.130	.130
19	.020	.060	.030	--	--
20	.490	.380	.540	.870	.870
Total	1.000	1.000	1.000	1.000	1.000
D-4b/					
22	.294	.294	.294	.294	.294
26	.023	.023	.023	.023	.023
31	.400	.400	.400	.400	.400
33	.179	.179	.179	.179	.179
34	.104	.104	.104	.104	.104
Total	1.000	1.000	1.000	1.000	1.000
D-4b/					
22	.199	.199	.301	.362	.362
28	.236	.236	.455	.422	.422
31	.565	.565	.244	.216	.216
Total	1.000	1.000	1.000	1.000	1.000
D-4b/					
28	.690	.550	.748	.508	.508
31	.310	.450	.252	.492	.492
Total	1.000	1.000	1.000	1.000	1.000
D-4b/					
25	.557	.573	.784	.784	.784
30	.443	.427	.216	.216	.216
Total	1.000	1.000	1.000	1.000	1.000

a/ Dashes indicate zero.

b/ D-4 includes areas 21-35; areas 21, 23, 24, 27, 29, 32, and 35 are not affected by moisture.

$$H_{3j} = \frac{AP_j}{\sum_{j=12}^{20} AP_j} H_3$$

where AP_j is acres planted in area j, and H is acres harvested. This rule merely states that each area harvests the proportional of the district's total that is represented by its contribution to the district's total acreage.

When the moisture index is positive, the district harvest quantities determined previously are allocated to the production areas as indicated by the proportions in Appendix Table D–8.

The *D–4* harvest allocation rules for July–September reflect a desire to harvest hot climate areas at maximum receiving station capacity to complete harvest before the quality of the crop drops. For Areas 21, 23, 24, 29, 32, and 34, the rule is to set the quantity harvested (H_{4j}) equal to receiving station capacity. The rule for Areas 22, 26, 27, 28, 31, and 33 is

$$H_{4j} = P_{4j} [H_4 - (H_{4,21} + H_{4,23} + H_{4,24} + H_{4,29} + H_{4,32} + H_{4,34})]$$

where P_{4j} is an allocation proportion which reflects availability of beets in different areas at different times and the desire to complete harvest in areas likely to be affected by rain. This rule may be clarified by pointing out that the harvest in D–4 is composed of two parts––the quantity allocated to areas operating at receiving station capacity (the total of the values within the parentheses) and a residual quantity allocated to the remaining stations. The values of P_{4j} are given in Appendix Table D–9. The nonavailability of beets to harvest is indicated by proportions not being listed for that area. The values of time period 10 continue until the fall harvest is completed. When an area completes harvest, the P_{4j} value for that area is set at zero, and its allocation proportion is given to other areas in proportion to their contribution to the total.

When the model is operating on a daily basis (October–April), the allocation of the district harvest to areas depends on the value of the moisture index. If the moisture index is zero, the allocation is made on the basis of the proportions in Appendix Table D–9. If the moisture index is positive, the allocation is determined by applying the proportions given in Appendix Table D–8. In Appendix Table D–8 there are four sets of proportions for D–4. The computer program counts the number of areas in D–4 where harvest remains and branches to the appropriate set of proportions. If there are over five areas remaining, the top set is used. If there are only five, it branches to the second set; and if there are either three or four left, it branches to the second set. If there are less than three areas, then it branches to the bottom set.

APPENDIX TABLE D-9

Proportion of Residual Quantity Harvested in D-4 in Specified Production Areas and Various Time Periods

Production area	Time period									
	1	2	3	4	5	6	7	8	9	10+
	proportion									
22	--[a]	--	--	--	--	--	.020	.080	.160	.160
26	.080	.080	.040	.050	.080	.110	.110	.090	.090	.090
27	.060	.100	.330	.210	.210	.240	.180	.170	.180	.180
28	--	--	--	--	--	--	--	--	--	.210
31	.860	.700	.560	.600	.570	.540	.510	.430	.390	.180
33	--	.120	.070	.140	.140	.110	.180	.230	.180	.180
TOTAL	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

a/ Dashes indicate zero.

For Area 35 (Imperial), the quantity harvested is the quantity needed to operate F–4 (Appendix Table D–3).

Delivery Routes and Methods.––Two types of decisions are involved: routes from production areas to receiving stations (R.S.) and routes and means of shipment from receiving stations to factories.

1. Production areas to receiving stations: The 35 production areas deliver the harvested beets to 27 receiving stations. Each station is numbered according to the area in which it is located. Appendix Table D–10 gives the route assignments specified by the processor based on past experience. During periods of low volume or when certain factories are being supplied, it may be economical to shut down some receiving stations and to divert trucks to other stations or directly to the factory. There are four stations so affected––13, 14, 17, and 18. The rules for determining these alternate routes are as follows:

Area 13

During February–June, deliver to R.S. 13

During July–January (if harvesting), deliver to R.S. 20 if going to factory 3; deliver to R.S. 17 if going elsewhere

Area 14

Deliver to R.S. 20 if going to F–3

Deliver to R.S. 14 if going elsewhere

Area 17

Deliver to R.S. 20 if going to F–3

Deliver to R.S. 17 if going elsewhere

Area 18

Deliver to R.S. 20 if going to F–3

Deliver to R.S. 18 if going elsewhere

APPENDIX TABLE D-10

Delivery Routes From Production Areas to Receiving Stations

District and production area	District and receiving station
D-1	
1	1
2	2
3	3
4	4
D-2	
5	8
6	6
7	7
8	8
9	8
10	8
11	7
D-3	
12	20
13	13 (17, 20)[a]
14	14 (20)[a]
15	20
16	20
17	17 (20)[a]
18	18 (20)[a]
19	20
20	20
D-4	
21	21
22	27
23	23
24	24
25	25
26	26
27	27
28	31
29	29
30	30
31	31
32	32
33	33
34	34
35	35

a/ Alternate routes; see text.

2. *Receiving station to factory:* The shipment patterns and methods of transportation from receiving stations to factories are derived for each period as a linear programming solution which minimizes total transportation cost subject to the restrictions imposed by harvest decisions, factory requirements, and the source restrictions specified in Appendix Table D–3. Since the quantities harvested and factory needs change, a new solution is required for each period. In practice, the restrictions imposed by the previous source decisions specified in Appendix Table D–3, plus inspection of the transportation cost matrix (Appendix Table C–8), enable us to greatly reduce the size of the problem to be solved and make it unnecessary to obtain new solutions for all periods. The preprogramming restrictions thus obtained are summarized in Appendix Table D–11. If there are any quantities left unallocated after applying these rules, a linear programming solution is obtained to determine the final optimal routing.

Factory Shutdown and Startup Dates.––Each factory continues to operate in the fall until rain prevents further harvest and then resumes operation in the spring when the soil again becomes dry enough for harvest. The rules for stopping and starting are as follows:

1. *Fall shutdown:* If the date is November 15 or later and the district moisture index reaches or exceeds a critical level, harvest stops. The factory continues to operate until its inventory of beets is sliced and then shuts down. For control within the computer program, artificial variables are assigned values which indicate that harvest has stopped and then that the factory has been shut down. The critical moisture values, based on 1965–1970 average experience, are 1.19 inches for D–2; 1.07 inches for D–3; .82 inches for D–4. D–1 is not included since harvest has been completed by this time. However, D–3 is supplying F–1 at this time so, when harvest stops in D–3, F–1 must shut down also.

2. *Spring startup:* The processor goal is to start up as soon after a prespecified date as possible. A certain level of inventory must be accumulated first. The dates and inventory requirements based on historical practice are as follows:

Factory	Date	Required inventory (tons)
F–1	March II	5,550
F–2	March I	4,100
F–3	March I	3,150
F–4	March I	3,850

A control variable in the computer program is set to indicate that the factory can be reopened when a specified date is reached. At the same time, harvest operations are allowed to resume with processing starting when the factory inventory reaches the required level.

APPENDIX TABLE D-11

Preprogramming Decision Rules for Receiving Station to Factory Shipments

District	Allocation rules
D-1 Areas 1-4 Stations 1-4	All areas ship to F-1; 1-3 by rail, 4 by grower truck.
D-2 Areas 5-11 Stations 6, 7, and 8	All shipments from areas in D-2 eventually are delivered to the receiving station at F-2. Areas 5, 8, 9, and 10 ship directly to station 8 (factory station). Areas 7 and 11 are received at station 7, area 6 at station 6, and then are shipped by transports to F-2. Any quantities that are shipped by rail from D-2 are shipped from the receiving station at F-2.
D-3 Areas 12-20 Stations 13, 14, 17, 18, 19, and 20	1. Ship F-3 requirements by truck from all stations (station 13 closed July I-January I). 2. Ship to other factories as follows: (a) November I-January I: Ship quantities required by F-1 by rail successively from stations 17, 20, 18, and 14 as needed. (b) January II-June II: Ship quantities required by F-1 by rail successively from stations 13, 17, 20, and 14 as needed. Quantities to F-2 and F-4 are shipped via rail successively from stations 18 and 20 as needed.
D-4 Areas 21-34 Stations in all areas except 22 and 28	Ship from D-4 to F-4 successively from stations (if operating) 31, 25, 30, 27, 34, 26, and 33 in that order as needed. From stations 25, 30, 27, and 34 by transport; 26 and 33 by rail, with deliveries to station 31 by grower truck.

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